WOODS HOLE OCEANOGRAPHIC INSTITUTION

Reference No. 65-12

OCEANOGRAPHIC AND UNDERWATER ACOUSTICS RESEARCH

conducted during the period
1 May - 31 October 1964

WOODS HOLE, MASSACHUSETTS

WOODS HOLE OCEANOGRAPHIC INSTITUTION
Woods Hole, Massachusetts

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Submitted to Undersea Warfare Branch
Office of Naval Research

Under Contracts Nonr-4029(00)NR260-101 and Nonr-3243(00)NR260-108

March 1965

In citing this report in a bibliography, the references should be followed by the phrase UNPUBLISHEI MANUSCRIPT, which is in accordanc with bibliographic practice.

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ABSTRACT

Geophysical investigations were carried out aboard R/V CHAIN in the Indian Ocean, the Mediterranean Sea, and the North Atlantic Ocean. Observations underway were continuous seismic profiling, gravity, magnetic, and echo sounding measurements. At stations rocks were dredged, cores were taken (about 10 meters long, photographic montages of the sea floor were made, and the sound velocity of the water was measured as a function of depth.

Progress is being made in filtering and correlation techniques for seismic profiling, while seismic receiving arrays were improved to make them quieter.

The analysis of internal wave data is continuing, but further observations at sea will be required in order to fully understand the mechanism of propagation.

Seven papers were published during this period and thirteen were submitted for publication. These papers are concerned with seismic profiling, seismic refraction profiles, sediment ponding, sound transmission, thermal fronts, and biological papers dealing with sound production by marine mammals and deep-sea fish natural history gained from bottom photographs.

A new thermistor string intended to replace and improve upon the original thermistor chain was the principal new instrumental development.

INTRODUCTION

This report is an account of activities under Contracts Nonr-4029 (also Nonr-1367) and Nonr-3243 with the Office of Naval Research for the period 1 May 1964 to 31 October 1964. This research is carried out mainly within the Department of Geophysics. The principal project of the Department has been completion of the work on R/V CHAIN in the Indian Ocean (Cruise #43). On June 4 the ship began the voyage home to Woods Hole via the Red Sea, the Mediterranean Sea and the North Atlantic Ocean. The scientific program of this portion of the expedition is described in the Cruise section of this report.

A second major expedition was also mounted by the Geophysics Department in cooperation with the Applied Oceanography Department. Cruise #11 of ATLANTIS II is not detailed in this report as the cruise was separately sponsored. However, since a discussion of the sound velocity profiles taken over the ocean area between Bermuda and the Antilles is pertinent to this contract, brief summaries of the work (sponsored by ONR contract Nonr-2866) are presented in the Physical Oceanography section of this report. Additional information about ATLANTIS II Cruise 11 may be found in the cruise report (in preparation).

These expeditions, and short cruises on GOSNOLD so occupied the staff as to reduce the development of new instruments. Nevertheless, great progress has been made toward realizing a long-sought new towed thermistor string. Eventually we expect this instrument to permit the recording of vertical temperature profiles up to a kilometer deep. While we are confident that excellent data can be taken while the string is under tow at speeds of several knots, we do not know whether, for example, depths as great as a kilometer can be achieved routinely when the tow is proceeding as fast as to twelve knots.

Analogous remarks apply to new developments in seismic reflection profiling in which much has been learned about quiet towing long arrays of hydrophones. The practical towing speed of the year seems to be about eight knots, but there are promising indications that those arrays will tow quietly enough for recording reflections from deeper than one or two kilometers below the sea floor at the highest ship speeds ordinarily employed with CHAIN or ATLANTIS II.

Despite the preoccupation with sea-going during this period, seven papers have been published, thirteen more have been submitted for publication and eight technical reports have been distributed (see lists on pages 2-6). Analysis of sound transmission and reverberation measurements has progressed, as have a variety of continuing researches in the fields of geology, geophysics, biology and physical oceanography. Details of these activities are discussed in this report.

PAPERS

(A) Published

WHOI Contr. No. 1441. A Method for Determining the Geographical Position of Deep Towed Instruments by Lincoln Baxter II. Navigation: Journal of The Institute of Navigation, Vol. 11, No. 2, pp. 85-98, 1964.

WHOI Contr. No. 1459. Seismic Refraction Observations on the Continental Boundary West of Britain by E. T. Bunce, S. Crampin, J. B. Hersey, and M. N. Hill. Journal of Geophysical Research, Vol. 69, No. 18, pp. 3853 - 3863, Sept. 1964.

WHOI Contr. No. 1464. Cenomanian (cretaceous) Foraminifera from the Puerto Rico Trench by Ruth Todd and Doris Low, Deep-Sea Research, Vol. 11, No. 3, pp. 395-414, July 1964.

WHOI Contr. No. 1465. A Shear Pin Weak-Link Assembly for Oceanographic Use by F. R. Hess. Deep-Sea Research, Vol. 11, No. 4, pp. 623-624, August 1964.

WHOI Contr. No. 1472. Oceanic Thermal Fronts in the Sargasso Sea by A. D. Voorhis and J. B. Hersey. Journal of Geophysical Research, Vol. 69, No. 18, pp. 3809-3814, September 1964. (Also Contract Nonr-2866 and Nonr-2196.)

Deep Anchored Acoustic Buoy Navigation System by Willard Dow. U. S. Navy Journal of Underwater Acoustics, Vol. 14, No. 2, pp. 271-275, April 1964. (Also Contract Nonr-2196)

Deep-Towed Echo Ranging Vehicle by Willard Dow. U. S. Navy Journal of Underwater Acoustics, Vol. 14, No. 2, pp. 289-299, April 1964. (Also Contract Nonr-2196)

(B) Papers Submitted for Publication

WHOI Contr. No. 1484. Sediment Ponding in the Deep Ocean by J. B. Hersey. Submitted to the Bull. Geol. Soc. of America.

WHOI Contr. No. 1511. Navigational Techniques used in the THRESHER Search by S. T. Knott. Submitted to Navigation: Proceedings of the Institute of Navigation.

WHOI Contr. No. 1525. Some Deep Water Sound Transmission Paths South of Cyprus by Lincoln Baxter, Robert Brockhurst and Earl E. Hays. Submitted to Journal of the Acoustical Society of America.

WHOI Contr. No. 1527. Underwater Calls of *Leptonychotes* (Weddell Seals) by W. E. Schevill and W. A. Watkins. Submitted to Zoologica, N.Y. Dr. Carlton Ray New York Aquarium. (Also NSF Grant GA-141)

WHOI Contr. No. 1545. Serpentinized Peridotite from the North Wall of the Puerto Rico Trench by C. O. Bowin, A. J. Nalwalk, and J. B. Hersey. Submitted to Bulletin of Geological Society of America.

WHOI Contr. No. 1550. Underwater Calls of *Trichechus* (manatee) by W. E. Schevill and W. A. Watkins. Submitted to Nature, London, England.

WHOI Contr. No. 1569. A Continuous Seismic Profiler Survey of Oceanographer, Gilbert and Lydonia Submarine Canyons, Georges Bank by Michel Roberson, University of Kansas. Submitted to Journal of Geophysical Research.

The following papers were submitted under other sponsorships as noted:

WHOI Contr. No. 1402. A Photographic Survey of Benthic Fishes in the Red Sea and Gulf of Aden, with Observations on their Population, Density and Habits by N. B. Marshall and D. W. Bourne. Submitted to MCZ Bulletin. (NSF Grants G-20702 and GB-543)

WHOI Contr. No. 1437. Gular Musculature in Delphinids by Barbara Lawrence and W. E. Schevill. Submitted to M. C. Z. Bulletin. (NSF Grant G-6171)

WHOI Contr. No. 1544. On the Behavior of Certain Marine Organisms during the Solar Eclipse of July 20, 1963 by R. H. Backus, R. C. Clark, Jr. and A. S. Wing. Submitted to Nature. (Contract Nonr-2196 and NSF Grant GB-543)

Long Range Experiments in Transmission Correlation and Reverberation Directed by Members of WHOI for Project ARTEMIS by L. Baxter, H. S. Graham, and D. D. Caulfield. Submitted to U. S. Navy Journal of Underwater Acoustics. (Contract Nonr-2866)

A Real-Time Sound Spectrum Indicator by W. A. Watkins. Submitted to Bio-Acoustics. (Contract NObsr-89464)

A Variable Reluctance Hydrophone by W. A. Watkins. Submitted to Natural History. (Contract NObsr-89464)

REPORTS

(A) Unpublished WHOI Reports

WHOI Ref. No. 64-9. Track Charts, Bathymetry and Location of Observations. ATLANTIS II, Cruise 1, 21 February - 5 March 1963. 1st Phase, 11 March - 29 March 1963; 2nd Phase North Atlantic Ocean by J. K. Hall and R. M. Pratt.

WHOI Ref. No. 64-10. Track Charts, Bathymetry and Location of Observations CHAIN Cruise No. 36, North Atlantic Ocean, Outer Ridge, Barracuda Fault, 4 June - 10 July 1963 by W. M. Dunkle, R. J. Cotter and D. L. Presberg. (Also NSF Grant GP-1123)

WHOI Ref. No. 64-22. Narrative of CHAIN Cruise #21 - August - December 1961 dtd June 1964 by J. B. Hersey, E. E. Hays and A. D. Voorhis. (Contract Nonr-1367, Nonr-2196, and NObsr-72521)

WHOI Ref. No. 64-24. Track Charts, Bathymetry and Location of Observations CHAIN Cruise No. 39, Northwest Atlantic Ocean, Continental Slope, and Rise Southeast of Cape Cod, Abyssal Hills, Southeast of Bermuda, 23 August - 23 September 1963 by D. L. Presberg and W. M. Dunkle.

WHOI Ref. No. 64-28. Sweep-Synchronized Positionable Trigger and Supplementary Components by W. E. Witzell.

WHOI Ref. No. 64-30. Narrative of CHAIN Cruise #17 Phase I, St. George, Bermuda, to Freetown, Sierra Leone, 19 February - 22 March 1961 by A. D. Voorhis and E. T. Bunce dtd June 1964.

The following reports were completed under other sponsorships as noted:

WHOI Ref. No. 64-5. Current Studies South of Bermuda by John G. Bruce, Jr. (Contract Nonr-2866)

WHOI Ref. No. 64-25. Track Charts, Bathymetry and Location of Observations ATLANTIS II Cruise 6, Second Leg, North Atlantic Ocean, Outer Ridge North of Puerto Rico, 29 May - 17 June 1963 by R. J. Cotter and W. M. Dunkle. (NSF Grant GP-1123)

(B) WHOI Technical Memoranda

Tech. Memo #7-64. Cruise Plans for R/V CHAIN Cruise No. 43 - Beirut, Lebanon to Woods Hole, Mass. dtd May 1964 by J. B. Hersey.

Tech. Memo #10-64. Cruise Plans for ATLANTIS II Cruise No. 11 - 17 June to 10 August 1964 dtd June 1964 by John C. Beckerle.

CRUISES

A. Introduction

On CHAIN Cruise #43, 15 February - 21 August 1964, geophysical and geological observations were made in the North Atlantic Ocean, the Mediterranean and Red Seas, and the Western part of the Indian Ocean, along the track Woods Hole - Ceuta (Spanish Africa) - La Spezia - Port Said - Aden - Victoria (Seychelles Islands) - Port Louis (Mauritius) - Victoria (Seychelles Islands) - Port Said - Beirut - La Spezia - Monaco - Plymouth (England) - Woods Hole. A series of charts (Salisbury and Goulet, Jr., 1964) at the end of this section indicate the course of this cruise.

Brief accounts by the Chief Scientists of scientific investigations on the legs of the cruise which fell in the period May - October are presented in this section.

B. Use of Vessels

Cruise No.	Date	Work Area	Principal Investigation	Scientist in charge
CHAIN 43	15 Feb-21 Aug. 1964	Atlantic Ocean, Mediterranean Sea, Red Sea, Indian Ocean	Seismic reflection & refraction; heat flow, dredging, magnetic & gravity measurements; bathymetry; sound velocity measurements; ambient noise; acoustic properties of the bottom; scattering layer; bottom photography; thermistor chain, water temperature.	S. T. Knott E. T. Bunce C.O. Bowin J.B. Hersey
CHAIN 44	29 Sept. - 13 Nov. 1964	Atlantic Ocean, Caribbean Sea	Bathymetry; gravimetry, magnetometry; sub-bottom reflection, coring, dredging, plankton tows; water sampling.	V.T. Bowen C.O. Bowin
GOSNOLD 46	6 July 1964	Buzzards Bay	Testing Equipment	L.C. Bennett
GOSNOLD 47	7-10 July 1964	Edge of Continental Shelf	Testing Equipment	D. Krotser
ATLANTIS II #11*	18 June - 8 Aug. 1964	Atlantic Ocean, Caribbean Sea	Sound velocity profile determination, current measurements, thermistor chain, seismic reflection, dredging, bottom photography.	J.G. Bruce J.C. Beckerle E.E. Hays

* This cruise was sponsored under contract Nonr-2866 and NSF Grant GP-2370.

C. CHAIN Cruise #43 Indian Ocean Expedition

La Spezia to Aden (Mr. Knott).

Departure of the R/V CHAIN from La Spezia was delayed about a week because of radar repairs. Therefore, the transit of the Mediterranean Sea to Port Said (March 14 - 19, 1964, see Fig. 1) had to be made rapidly and only those measurements which could be made at top ship speed could be taken. These included gravity and magnetic measurements, observations of near surface water temperatures, backscattering of light from a laser and continuous bottom profiling with the echo sounder. A considerable amount of data at 12 kc on the diurnal migration of the scattering layers was taken to provide late-winter seasonal information for R. G. Frassetto of SacLant, La Spezia, and for our own use.

The passage through Suez Canal was made smoothly and both gravity measurements and bathymetry were obtained. Bathymetry data were taken on two recorders so that one copy could be given to Dr. Ahmed Ammar of the Research Laboratory of the Suez Canal Authority in return for his interest in our work and his kind assistance.

Sufficient time was gained in the high speed run from La Spezia to allow a brief geophysical exploration of the Red Sea (see Fig. 2). During seven diagonal crossings of the median rift valley between the south end of the Gulf of Suez (lat. 27°30'N and lat 17°30'N) all the previously mentioned underway observations were for the most part continuously made. Crossings of the sea were planned to pass-over the locations of a number of the seismic refraction profiles made by R/V ATLANTIS and R/V VEMA in 1958 (Drake and Girdler, 1964) to compare the structure of the sub-seafloor rocks detected by the seismic profiler with that found by the seismic refraction studies. Again to gain time, seismic reflection profiling was omitted on one zig-zag and to the south of 17°30'N. Two stations were made, however, to instruct students in the use of dredges and to checkout the heat flow apparatus.

We arrived at Aden on March 28, 1964, about noon and docked at the British naval facility. The berth requested by us and graciously offered by the British was the one previously occupied by HMS OWEN and the location of their station to check-out their shipboard gravimeter.

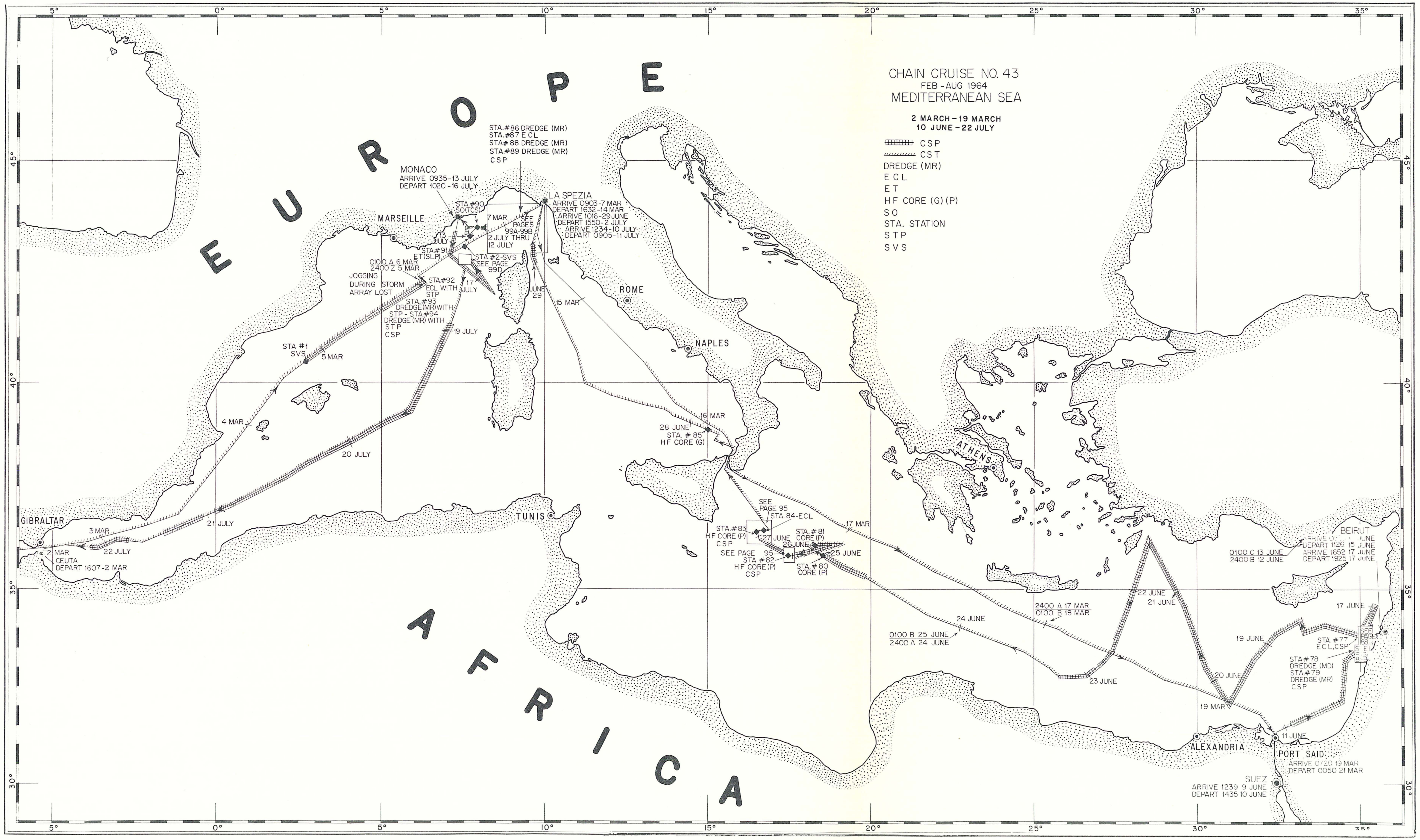


Fig. 1. CHAIN Cruise #43 - Mediterranean Sea.

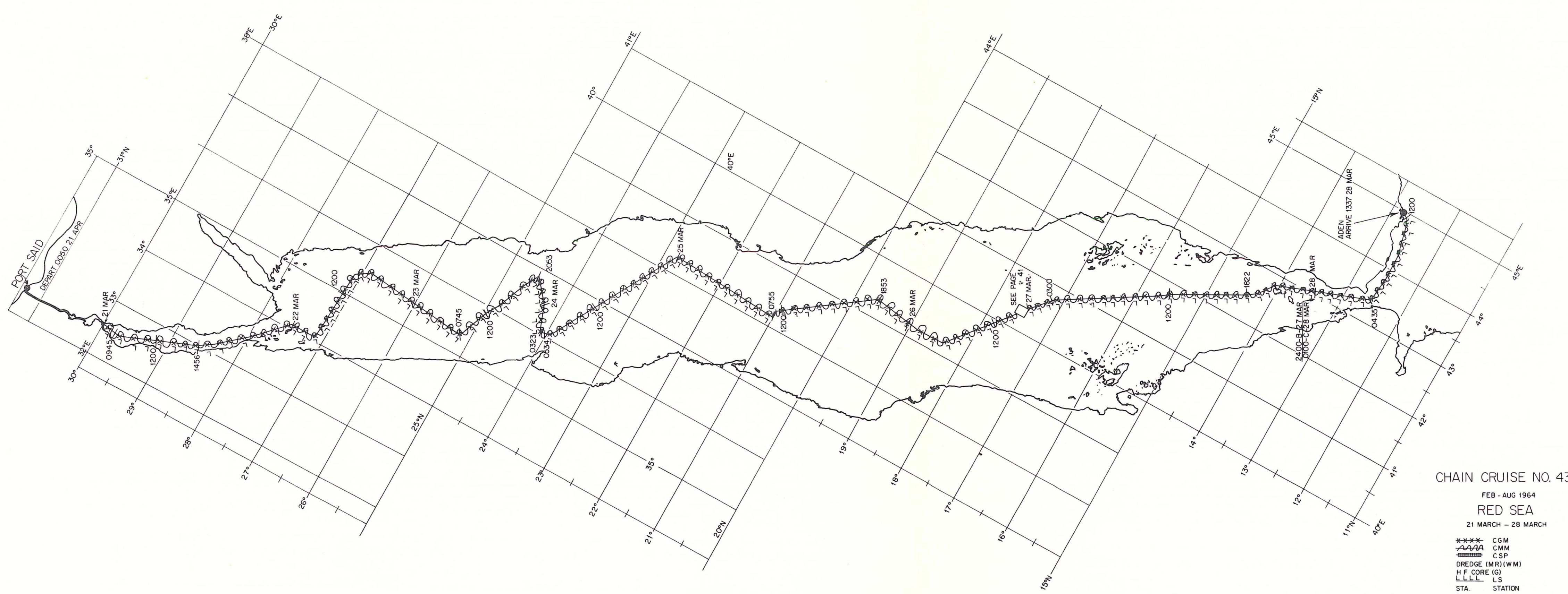


Fig. 2. CHAIN Cruise #43 - Red Sea (Southbound).

Aden to Beirut, Lebanon (Miss Bunce and Dr. Bowin).

The major portion of the scientific investigations conducted aboard R/V CHAIN in this period (30 March - 12 June) is reported in Section A under Submarine Geology and Geophysics (see Figs. 3 and 4). In addition to the observations presented there, an excursion was made to the vicinity of the Carlsberg Ridge during the return voyage from the Seychelles Islands to Beirut. (See report on magnetics program by Dr. Bowin in Section A, Submarine Geology and Geophysics.) Underway seismic observations were made in the Gulf of Aden on both transits.

Beirut, Lebanon to Plymouth, U. K. (Dr. Hersey).

The CHAIN departed from Lebanon on June 17, 1964 and terminated this major section of Cruise #43 on July 28, 1964 in Plymouth, U. K. (see Figs. 1 and 6). By far the major emphasis during this period was in the examination of the sea floor and the sediments and rock beneath by means of echo sounding, seismic reflection, gravity, and magnetic measurements, hereinafter referred to collectively as underway measurements. The individual investigations were, in order of execution:

1. The continental shelf and slope off the Lebanese coast.

2. The central and extreme eastern Mediterranean. During this phase underway measurements were taken along a track commencing off Beirut and passing 20 miles south of Cyprus, thence southwards to shallow water of the Nile Delta, thence northwestward to the deep basin just southeast of the island of Rhodes, and finally southwestward to the central eastern Mediterranean.

3. A detailed grid of observations covering the major part of the Ligurian Sea.

4. A reconnaissance profile from Monaco down the center of the Balearic basin (between Corsica and Sardinia and the Balearic Island), proceeding down the center of the Balaeric Basin and through the Strait of Gibraltar.

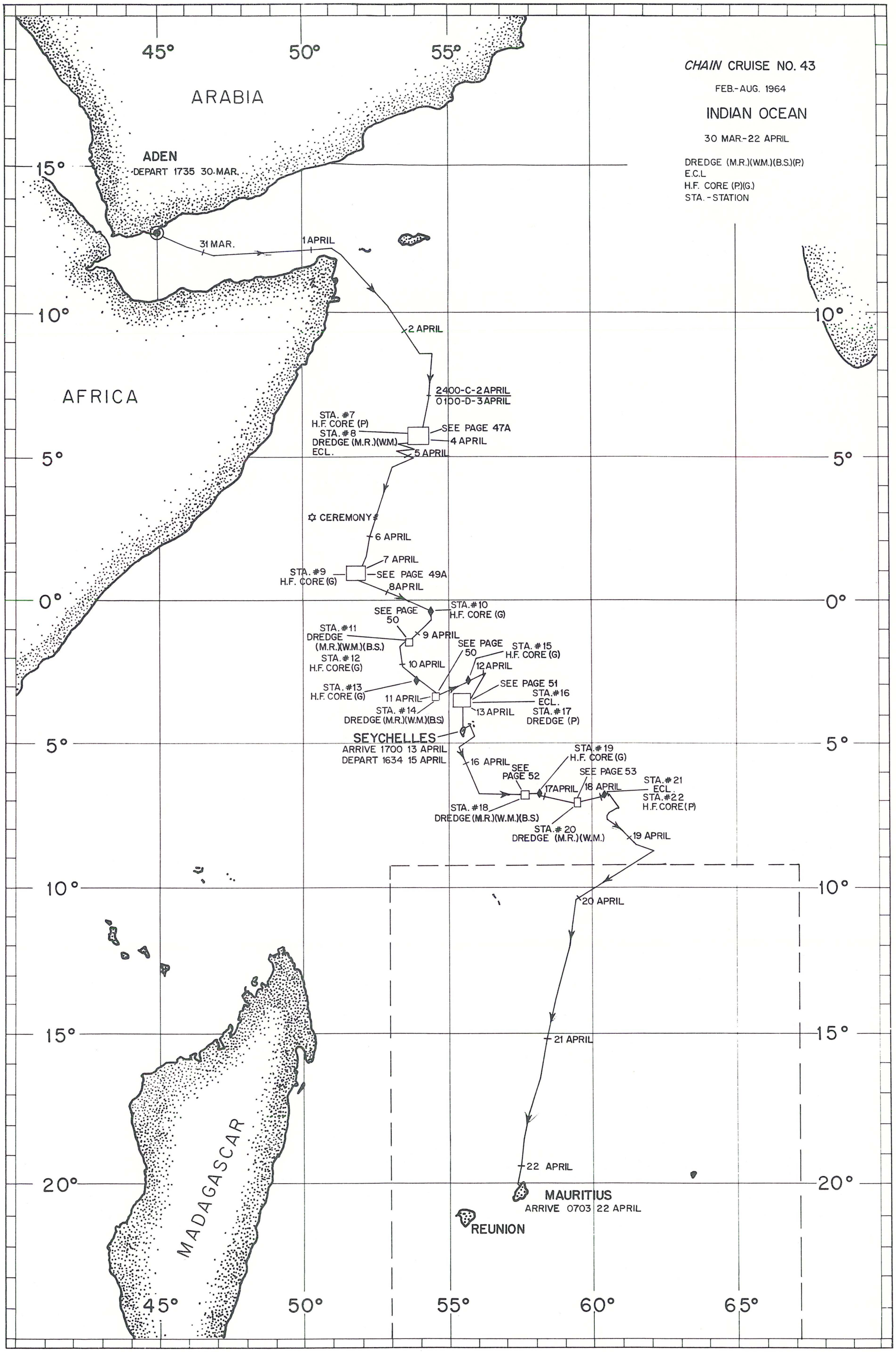


Fig. 3. CHAIN Cruise #43 - Indian Ocean (Southbound).

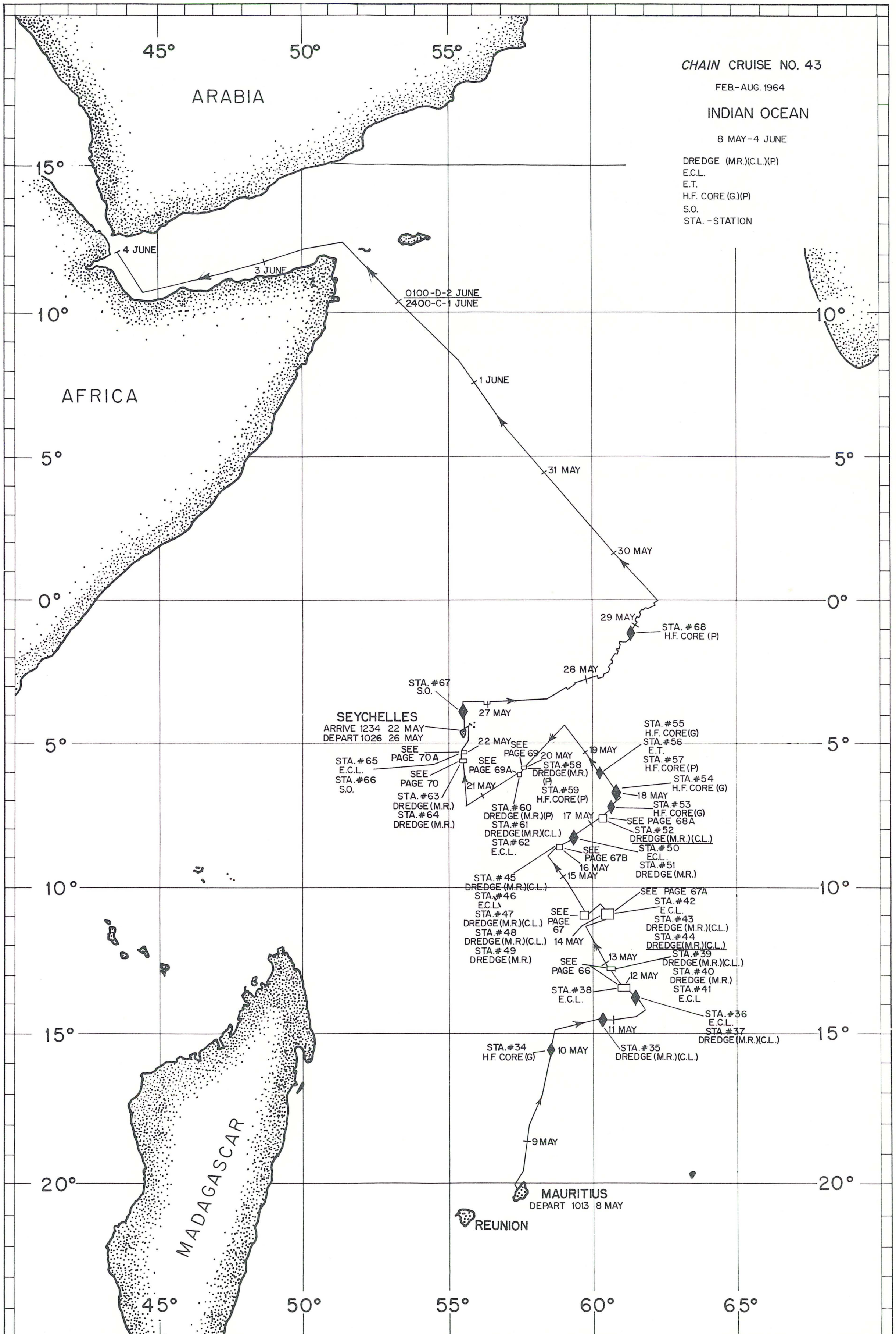


Fig. 4. CHAIN Cruise #43 - Indian Ocean (Northbound).

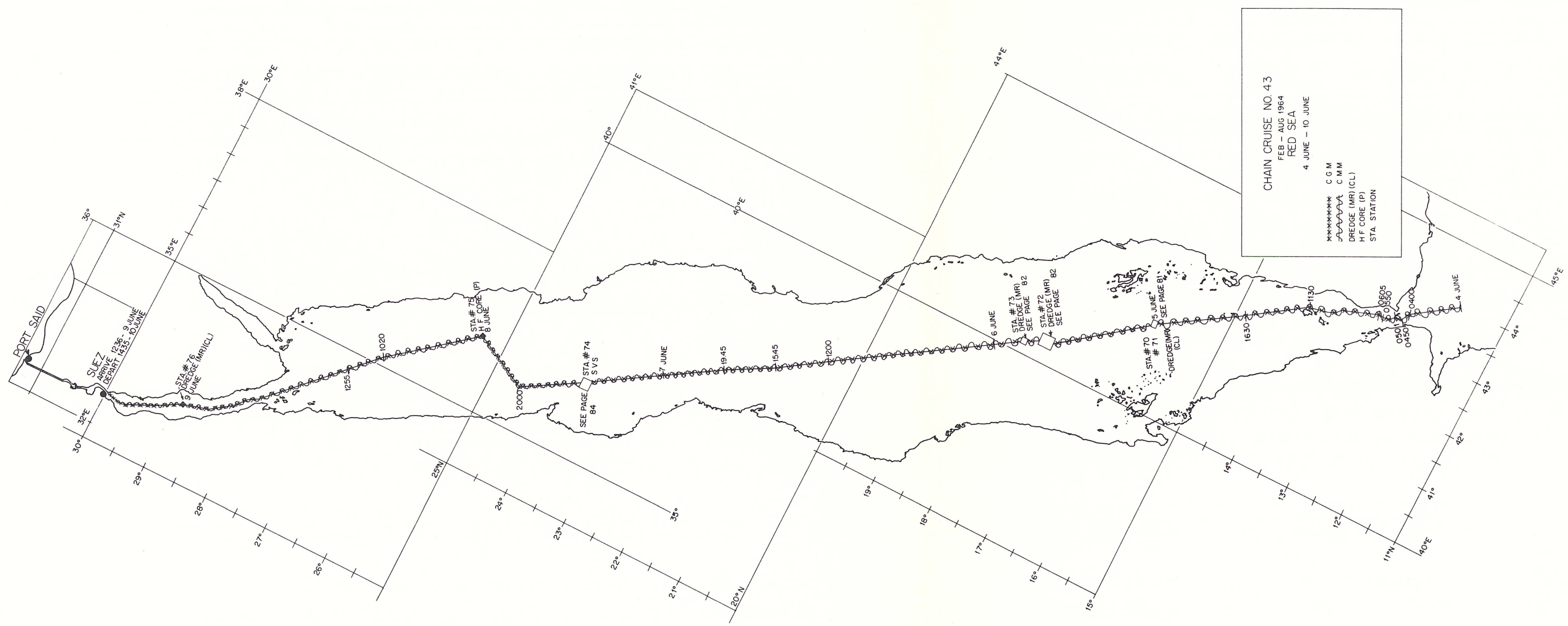


Fig. 5. CHAIN Cruise #43 - Red Sea (Northbound).

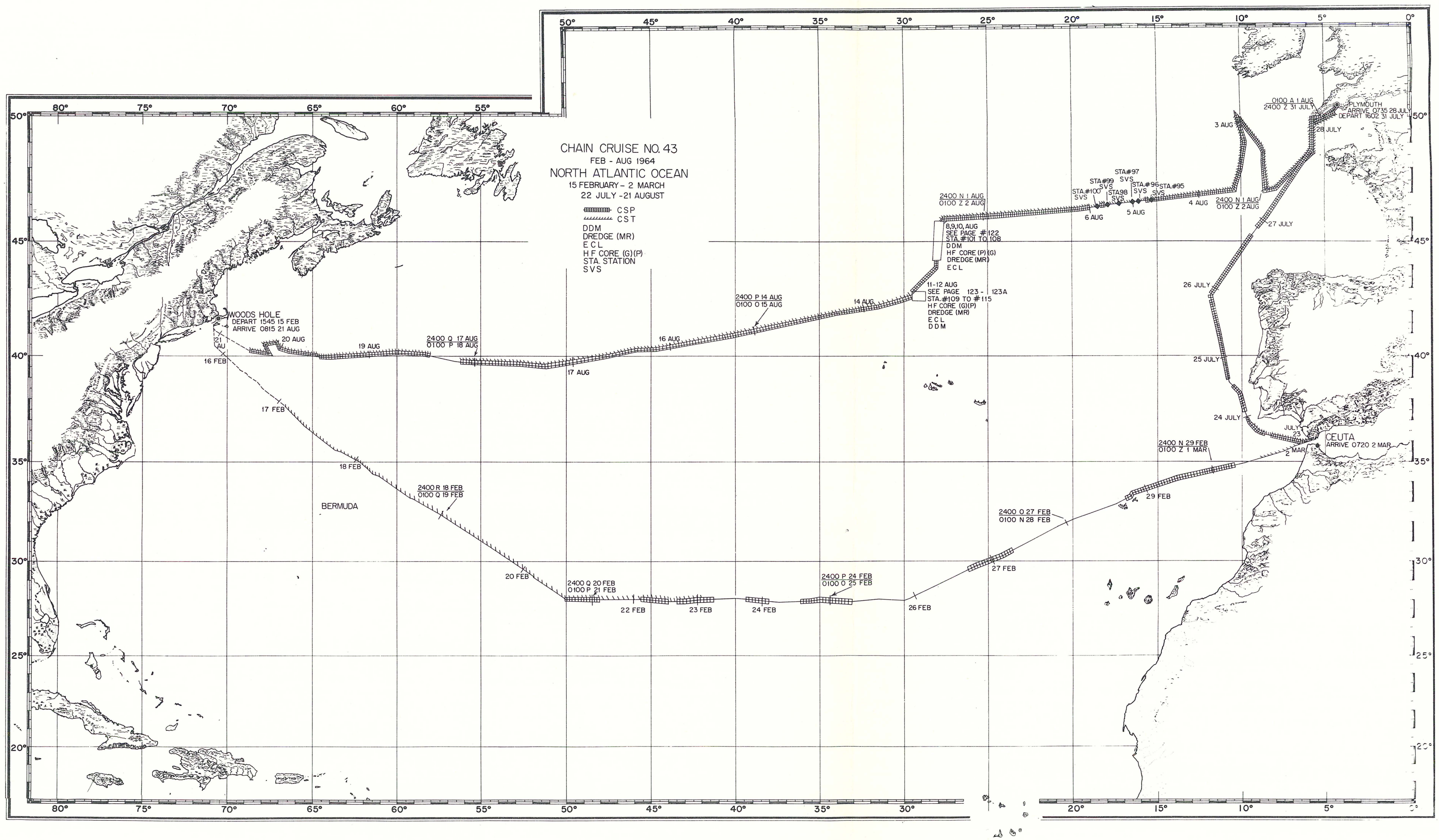


Fig. 6. CHAIN Cruise #43 - North Atlantic Ocean.

5. A single profile along the continental rise from the Strait of Gibraltar along the coast of Portugal and into deep water toward Galicia Bank (west of Cape Finisterre).

6. A single dog-leg profile across the top and southern and northern slopes of Galicia bank.

7. A single profile across the ocean basin of the Bay of Biscay.

8. Two profiles across portions of the English Channel.

From these observations the following data were obtained:

1. Precise echo soundings over the entire track.

2. Seismic reflections from the sea floor and from reflecting horizons down to depths below the sea floor varying from 0.2 to about 2 km. depending on the conditions of observations. Data is in the form of magnetic tape recordings covering the frequency band from about 25 to 2000 cps and in Precision Graphic recordings (PGR recordings) in selected frequency bands. We anticipate that the recordings on magnetic tape will supply data for the measurement of bottom reflectivity over much of the frequency band cited above. Both the tapes and the PGR records will be used in various studies of the acoustical properties of the sediments and rocks, and of the geologic structure.

3. The acceleration of gravity along the track. From this measurement free-air and Bouguer anomalies are automatically computed and plotted by the digital computer installed in CHAIN.

4. Total magnetic field strength along the ship's track. This quantity is automatically stored and plotted as in (3) above.

In addition to these observations the temperature of the sea water was recorded continuously at a nominal depth of 15 feet and at greater depths which varied between about 50 and 70 feet depending on the speed of the ship.

A few additional research projects were carried out at selected locations as follows:

1. Dredgings were made on the continental slope off Lebanon in an attempt to identify rock masses appearing to crop out on the slope.

2. In a large abyssal plain east of Sicily, seismic reflection measurements both with the Continuous Seismic Profiler and with the echo sounder were coordinated with the taking of four cores by means of a 50' piston corer. This research was intended to identify the bottom sediments responsible for acoustic echoes and to elucidate the processes governing the sedimentation of enclosed basins.

3. Rock dredgings and photographs were made on the continental slope west of Santa Lucia shoal and also on a similar but deeper slope at the edge of the abyssal plain in the Ligurian Sea. In both instances the purpose was to identify rock outcrops suggested by the seismic reflection records. Both were successful in obtaining rock samples, but the deeper dredging and camera station revealed only the presence of fossil single corals (Desmophyllum cristagalli) in about 1100 to 1200 fms. of water near the edge of the abyssal plain.

4. The investigation by continuous seismic profiler, dredge, and camera of an apparent outcrop in the abyssal plain between Monaco and Corsica which has the general appearance of a salt dome. No pictures or samples were obtained, but the many excellent reflection profiles suggest a structure similar to those in the Sigsbee Deep (Gulf of Mexico) considered to be salt domes by Maurice Ewing.

<u>Atlantic Leg, W. Plymouth - Woods Hole</u> (Dr. Chase).

During the westbound leg of CHAIN in August 1964 (Fig. 6) four investigations were carried out:

1. Three seismic reflection profiles were made across the seaward boundary of the European continental shelf west of Britany and Cornwall. The objective was to add to knowledge of the structure of the Mesozoic and Tertiary sedimentary strata which make up the top layer of the shelf and to trace the unconformity between these strata and underlying Paleozoic rocks.

The geological structure at the seaward edge of the shelf is of particular interest because it is desired to know the processes by which the shelf and slope are formed.

Two seismic reflection profiles were recorded over the continental slope and shelf of North America off Nantucket. A series of similar profiles further west were made by CHAIN on Cruise #39.

2. Five velocimeter lowerings to depths of from 500 to 2000 fathoms were made between long. 14°W and long. 19°W, and lat. 46°N and 47°N. The lowerings were spaced about 28 miles apart. The velocimeter lowering will provide data for a more extensive project.

3. Continuous seismic profiles were made from the European continental shelf to the Mid Atlantic Ridge at latitude 46°N, and from the Ridge to the North American Shelf between latitudes 40° and 42°. The profiles were intended to reveal the variations in thickness and the distortion of sedimentary layers overlying rugged, presumably volcanic rocks on the flanks of the Mid Atlantic Ridge, and the layering beneath the bordering abyssal plains. The records were marred by noise caused by excessive speed of the receiving array through the water. This was unavoidable because speeds of 11 to 13 knots were necessary to reach Woods Hole on time.

4. Heat flow, magnetic and gravity anomalies, bathymetry and petrology of the crest of the Mid Atlantic Ridge between 42° and 45°N were investigated. The objectives were:

a) to obtain information bearing on depth of origin of magma and age of the rocks of the ridge crest.

b) to ascertain whether the concept that the crest of the Mid Atlantic ridge is an area of high heat flow holds for the section of the ridge investigated.

c) to find the shape, extent and cause of magnetic anomalies over the crestal region.

Eight crossings were made across the crest between 42° and 45°N. The median valley, 7 to 15 miles wide, is flanked by ridges whose tops lie as high as 600 fathoms deep. The rugged bottom of the valley lies up to 1700 fathoms deep. Several attempts to measure heat flow in the valley failed, but one good measurement, made a few miles to the east, gave a normal value of heat flow. A radar buoy was laid at 42°39'N, 28°54'W, and the area within eight miles of the buoy was surveyed on a 2-mile apart east-west set of grid-lines. Figure 7 and 8 are contoured maps of bathymetry and magnetic field intensity in the surveyed area. Charts of this area, known as Chaucer Banks or Knolls, show soundings as shallow as 15 fathoms. However, the shoalest water sounded by CHAIN was 590 fathoms.

Four dredgings on the crestal area of the ridge yielded rock. Vesicular and glassy basalt and foraminiferal and coralline limestone are considered to have originated in the localities in which they were dredged, but angular and striated fragments of various other lithologies were dropped in the area, recently or during the Pleistocene ice ages, from icebergs by which they were transported from glaciated continental regions.

SUBMARINE GEOLOGY AND GEOPHYSICS

A. Investigation and Analysis

Geophysical Investigations of the Northern Somali Basin and Seychelles - Mauritius Ridge (Miss Bunce).

The following is a portion of the analysis resulting from the Indian Ocean Expedition by the R/V CHAIN cruise in 1964. It consists of the text of a scientific paper delivered at a discussion meeting of the Royal Society of London in November 1964 and submitted for publication in the Proceedings of the Royal Society. This work was jointly sponsored by ONR under Contract Nonr-4029 and the National Science Foundation under Grant GP-2370.

This portion of the cruise was largely supported by the National Science Foundation.

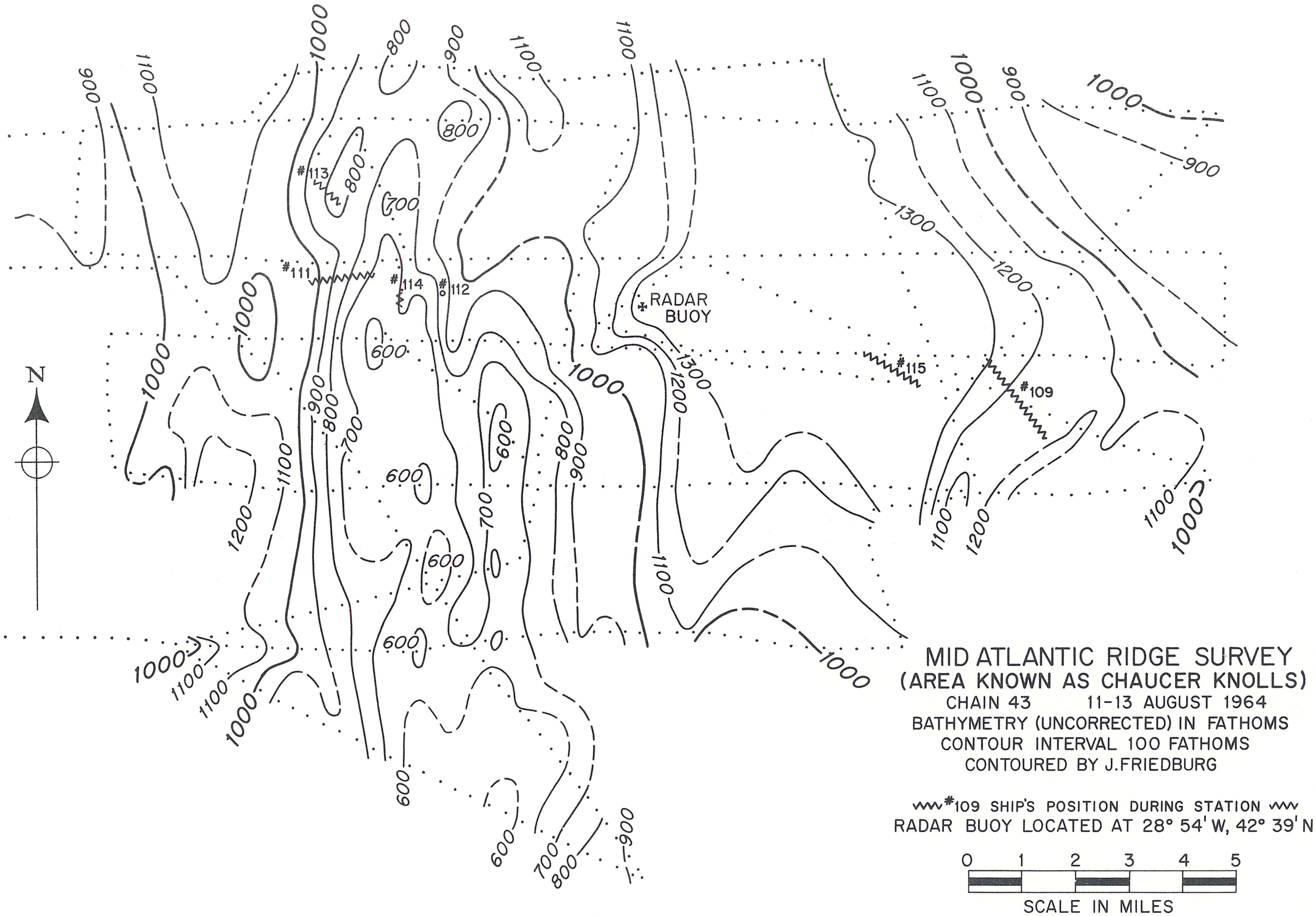


Fig. 7. Mid-Atlantic Ridge Survey (Bathymetry).

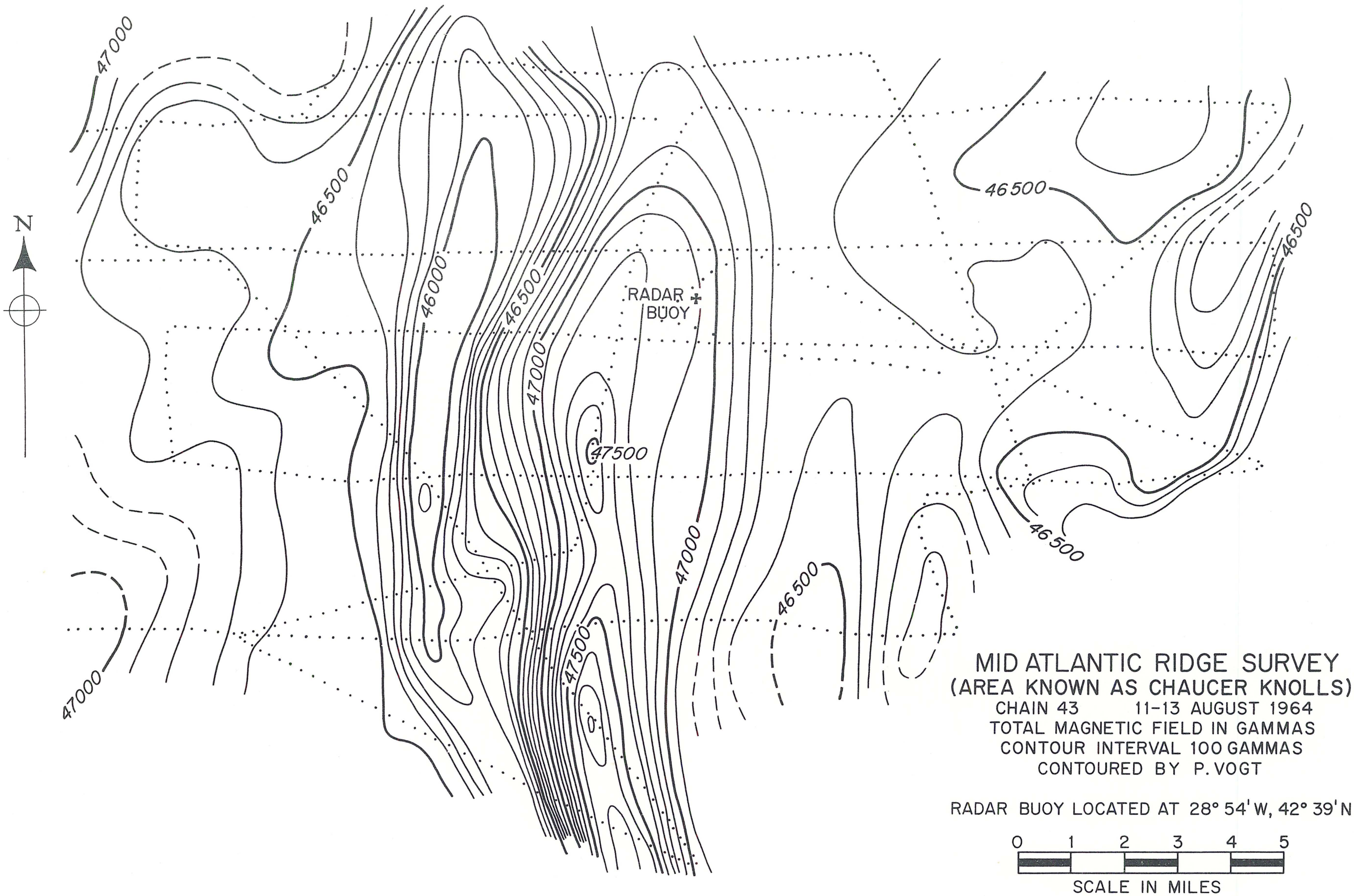


Fig. 8. Mid-Atlantic Ridge Survey (Magnetics).

a) Synopsis.

Geophysical investigations of the northern Somali Basin and the Seychelles-Mauritius Ridge conducted aboard R/V CHAIN of the Woods Hole Oceanographic Institution are described and some results presented. Gravitational and total magnetic fields and bathymetry were measured continuously, and continuous seismic reflection profiles were recorded over a major portion of the track. Cores, dredge samples, heat flow measurements, and underwater photographs were also obtained.

It is considered that the northern portion of the Somali Basin is a deep sedimentary basin partially enclosed to the east by a submarine ridge from which alkaline gabbro has been dredged and to the south by partially buried abyssal hills.

On the evidence from seven crossings of the Seychelles-Mauritius Ridge, it is proposed that the Ridge comprises two sections. The northern section, composed of nearly horizontally stratified rocks, extends from near the northern part of Saya de Malha Bank to the Seychelles Platform. The southern section is a linear, probably volcanic ridge that extends from north of Mauritius through Saya de Malha Bank, and may continue as a subsurface feature to the northeast. The two sections abut near Saya de Malha Bank, forming a continuous topographic feature.

A broad area of the northwest Indian Ocean was investigated during April and May 1964 on a voyage of R/V CHAIN (Fig. 9). This report presents preliminary results and some conclusions concerning structural relationships for two particular areas: the northern Somali Basin and the Seychelles-Mauritius Ridge.

Underway observations discussed here are measurements of free-air gravity anomaly and total intensity magnetic field with a LaCoste-Romberg gravimeter and proton magnetometer respectively, bathymetric profiles determined by precise echo-sounding, and continuous seismic profiling (spark source) to record the deeper sub sea-floor structure (Hersey, 1963). Cores, dredge samples, and underwater photographs also contribute to the findings.

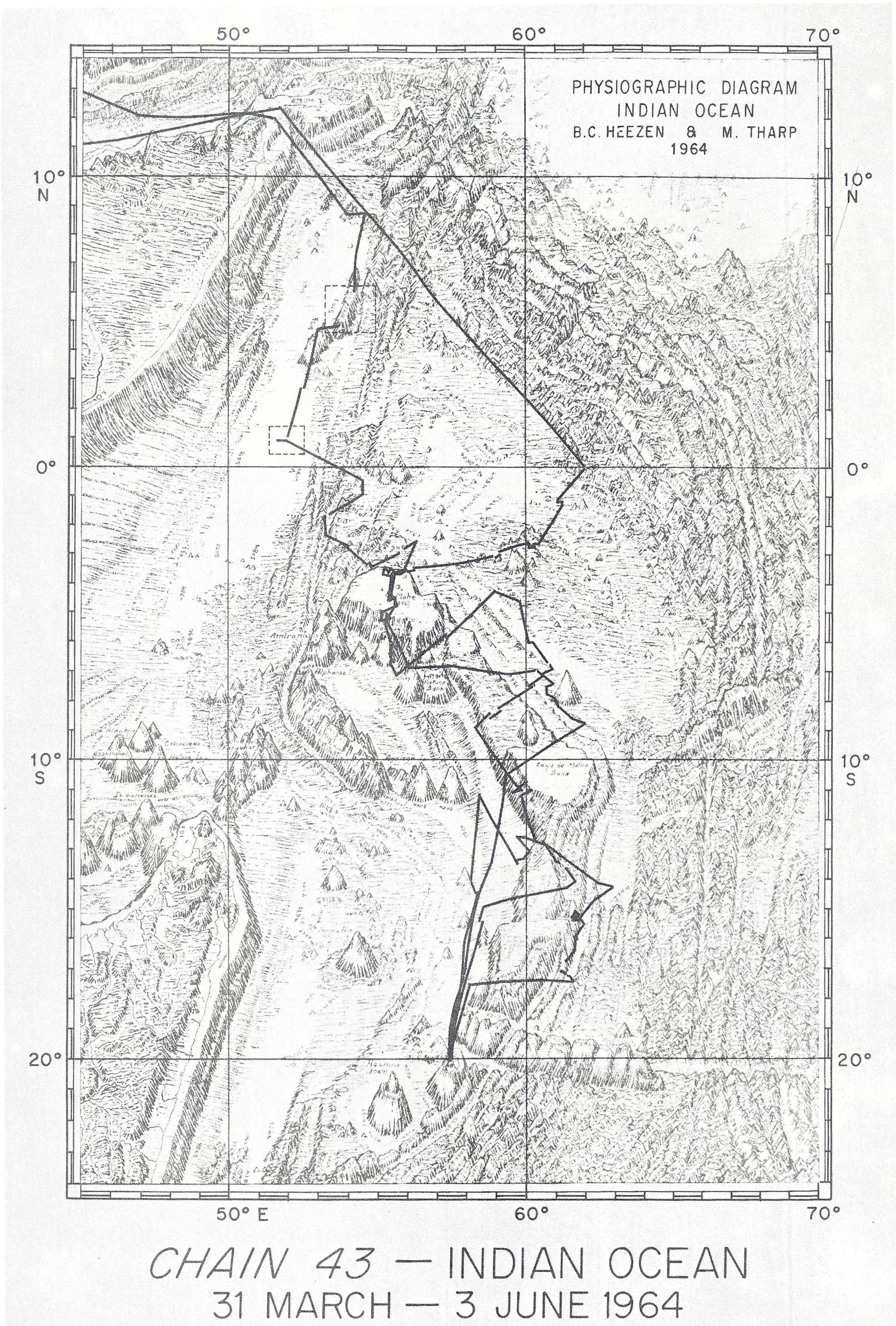


Fig. 9. Indian Ocean (Physiographic Diagram).

b) Northern Somali Basin.

A number of traverses were made across Owen Ridge, near the eastern border of the northern Somali Abyssal Plain. The traverses were planned to determine whether separated hills or sea mounts shown on an earlier version of the diagram of figure 9 are instead part of a ridge and to investigate the associated magnetic anomaly. The ridge was traced as a topographic feature of 1000 to 1700 fm relief above the abyssal plain as far south as 3°30'north latitude. The magnetic anomaly associated with the ridge is lower than would be expected for a recent volcanic feature. This interpretation is reinforced by samples of alkaline gabbro, a rock of deep seated origin, dredged from the southeastern slope of the ridge between the depths indicated at 5.75 and 6.75 sec. reflection travel time (Figure 10d).

Profiles of the total-field magnetic intensity, free-air gravity anomaly, and sub sea-floor structure of the continental rise south of Socotra and of the Somali abyssal plain as far south as Owen Ridge are shown in Figure 10. The significant departures from regional trends are a magnetic anomaly of 300 gamma associated with the subbottom structure (a), the increase in the negative free-air anomaly over the deep, uniform layers of the abyssal plain (b), and the relatively low amplitude magnetic anomaly over the northwestern slope of Owen Ridge (c).

Echo soundings made with very short pulses reveal sequences of thinly layered sediments at the top of the subbottom sequence which are continuous over great distances on the continental rise (Fig. 11, top) and on the abyssal plain to the south. The deeper structure of the northern basin, which extends as far south as Owen Ridge, is shown by the seismic reflection profile. Flat uniform layers 2 seconds of travel time below seabottom are evident. A photograph of a portion of the original record, obtained over the continental rise, is shown in Figure 11 (bottom).

There is a marked difference between the subbottom structure north and south of Owen Ridge. The topography to the south is slightly rougher than to the north, although some shallow stratification occurs between small hills (50 - 200 fm.) rising above the bottom. A reflection more or less continuous at 0.25 second after the bottom echo is shown on the reflection profiles, but the deep echoes from uniform reflectors similar to those of the northern part of the basin are not present.

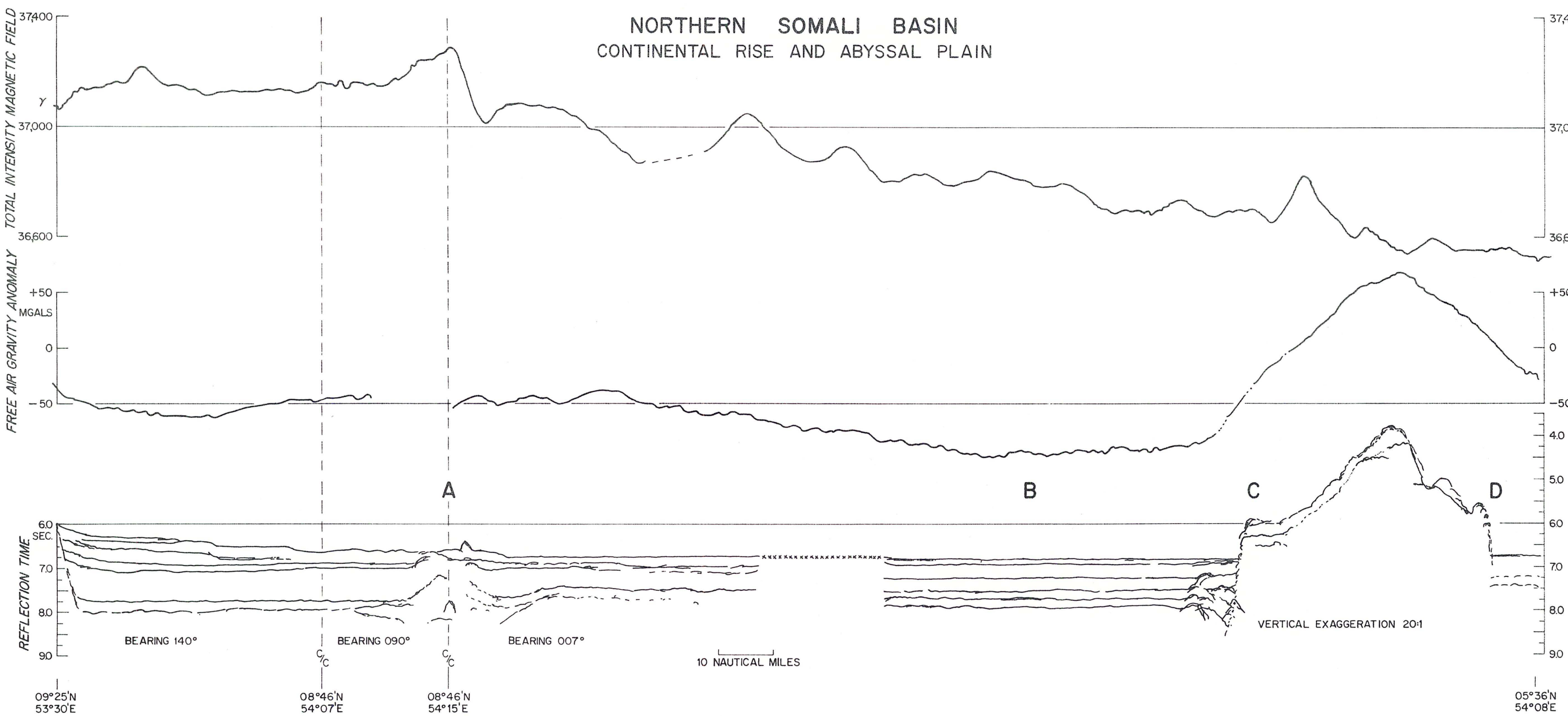


Fig. 10. Northern Somali Basin.

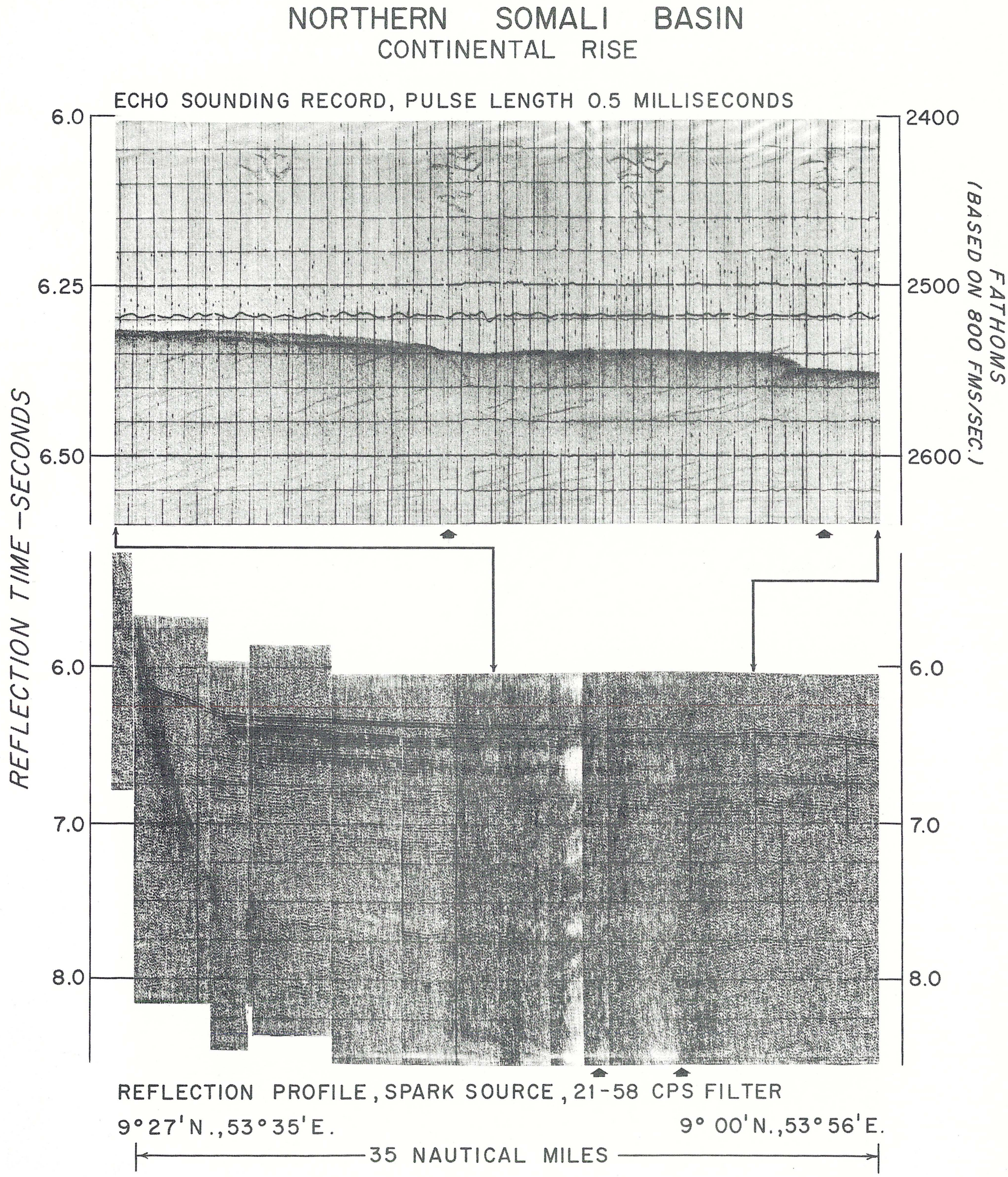


Fig. 11. Somali Abyssal Plain.

Instead, echoes suggesting a rough reflecting surface at an average delay of 1 second after the sea bottom echo, with relief of 0.5 second or greater, suggests buried and partially buried hills. The section resembles those found in areas of abyssal hills in the North Atlantic.

It appears that the northwest portion of the Somali Basin is a deep sedimentary basin partially enclosed to the east by Owen Ridge and to the south by buried and exposed abyssal hills. Corroboration of this hypothesis is furnished by seismic reflection profiles recorded during two traverses made by R/V VEMA of Lamont Geological Observatory (Langseth, personal communication, 1964). The VEMA profiles show the structure west of Owen Ridge to be the same as that to the north, already described, while to the southwest it resembles the section of abyssal hills. These structures to the south may be an extension of the Ridge.

c) The Seychelles-Mauritius Ridge.

Seven crossings were made of the Ridge lying between the Seychelles Islands and the island of Mauritius. The bearings of the crossings vary, some being less normal to the trend of the Ridge than others.

The profiles of Figure 12 present sections across the northern part of the Ridge, from the Seychelles Platform to Saya de Malha Bank. The effects of the regional gradient on total intensity magnetic field and those of topography on the free air gravity anomaly are clearly to be seen. A possible magnetic anomaly is associated with the Ridge or series of hills which rise from the western slope of the central Ridge. This anomaly is small on profile 1 but more distinct on profiles 2 and 3.

The seismic reflection profiles over the central Ridge on the three northern crossings (profiles 1 - 3) although not presented in Figure 12, show rather uniform echo sequences suggesting sub sea-floor layering. The echoes arrive up to 0.5 sec. after the bottom echo.

In profile 4, across the northern section of Saya de Malha Bank, and in the three profiles to the south of it shown in Figure 13 the central part of the Ridge has relatively steep slopes and a flat top. The seismic reflection records contain no evidence that the flat top is underlain by flat lying sediments: although the water depth is shallow, the bottom reflects

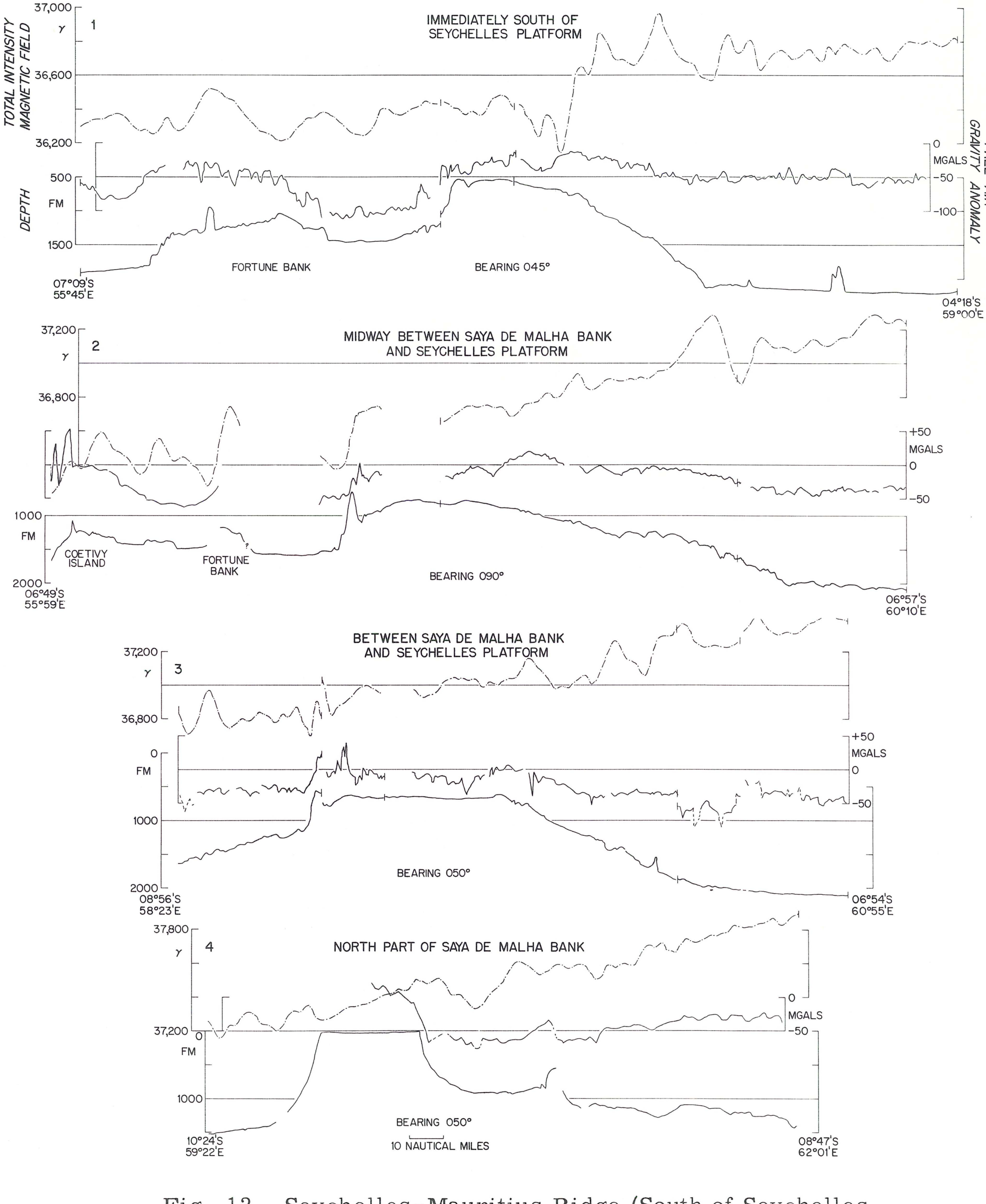


Fig. 12. Seychelles-Mauritius Ridge (South of Seychelles Platform).

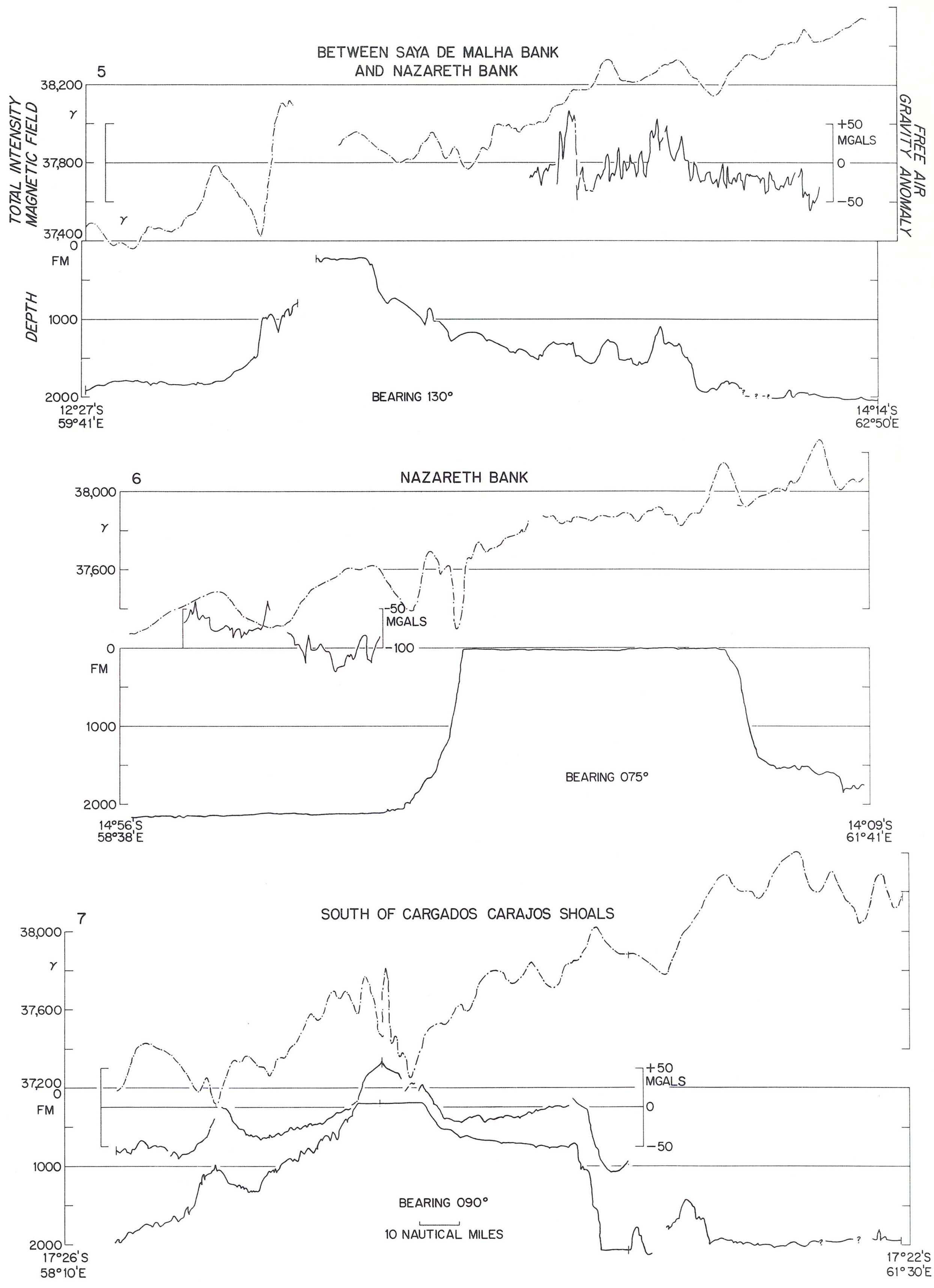


Fig. 13. Seychelles-Mauritius Ridge (South of Saya de Malha Bank).

sound so poorly here that only one multiple of the bottom reflection is detectable on the records, and it would be possible to detect flat lying subbottom reflectors if they existed.

In the three southern profiles (nos. 5 - 7, Fig. 13), as on Saya de Malha Bank, there is no seismic reflection evidence for layering of the flat, high central part of the Ridge. However, reflecting horizons with echo delays as great as 0.65 sec. beyond the bottom echo can be traced east and west up the flanks of the ridge to the 1000- or 700-fathom level on each of these crossings. Therefore it is tentatively concluded that the flat top is a product of erosion, not deposition. The fourth magnetic profile shows no high intensity anomaly over the central part of the Ridge. The corresponding gravity profile and others to the south are incomplete because rough seas encountered in this area prevented uninterrupted operation of the gravimeter.

The high amplitude magnetic anomalies associated with the center of the flat top of the Ridge in profile 7 and with its western edge in profiles 5 and 6 are in contrast with those of relatively low amplitude in profile 4.

Profile 7, shown again in Figure 14, presents the structure shown by the seismic reflection record. The distinctive feature is the layering suggested beneath the lower eastern part of the Ridge by echo sequences at 1.75 sec. (700 fm.) water depth. A layered section of the same thickness is suggested by the seismic records at the foot of the eastern slope of the Ridge, at a depth of over 2000 fathoms. Thus the eastern slope of the Ridge in this area may be a zone of faulting. It is also possible, however, that the higher layered sequence consists of sediments derived from the central part of the Ridge, and, further, that the deeper sequence is not related to it, but is derived from the area south of the Ridge (Fig. 9), or from elsewhere.

Twenty-five dredge lowerings were made, on and along the flanks of the Seychelles-Mauritius Ridge. Except for one small piece of granite SE of Seychelles Platform and one pebble of volcanic (?) rock obtained northeast of Saya de Malha Bank, all the samples obtained are limestone, coral fragments, or calcareous sand whose foraminifera have been identified as Recent by Dr. Wm. A. Berggren (personal communication, 1964).

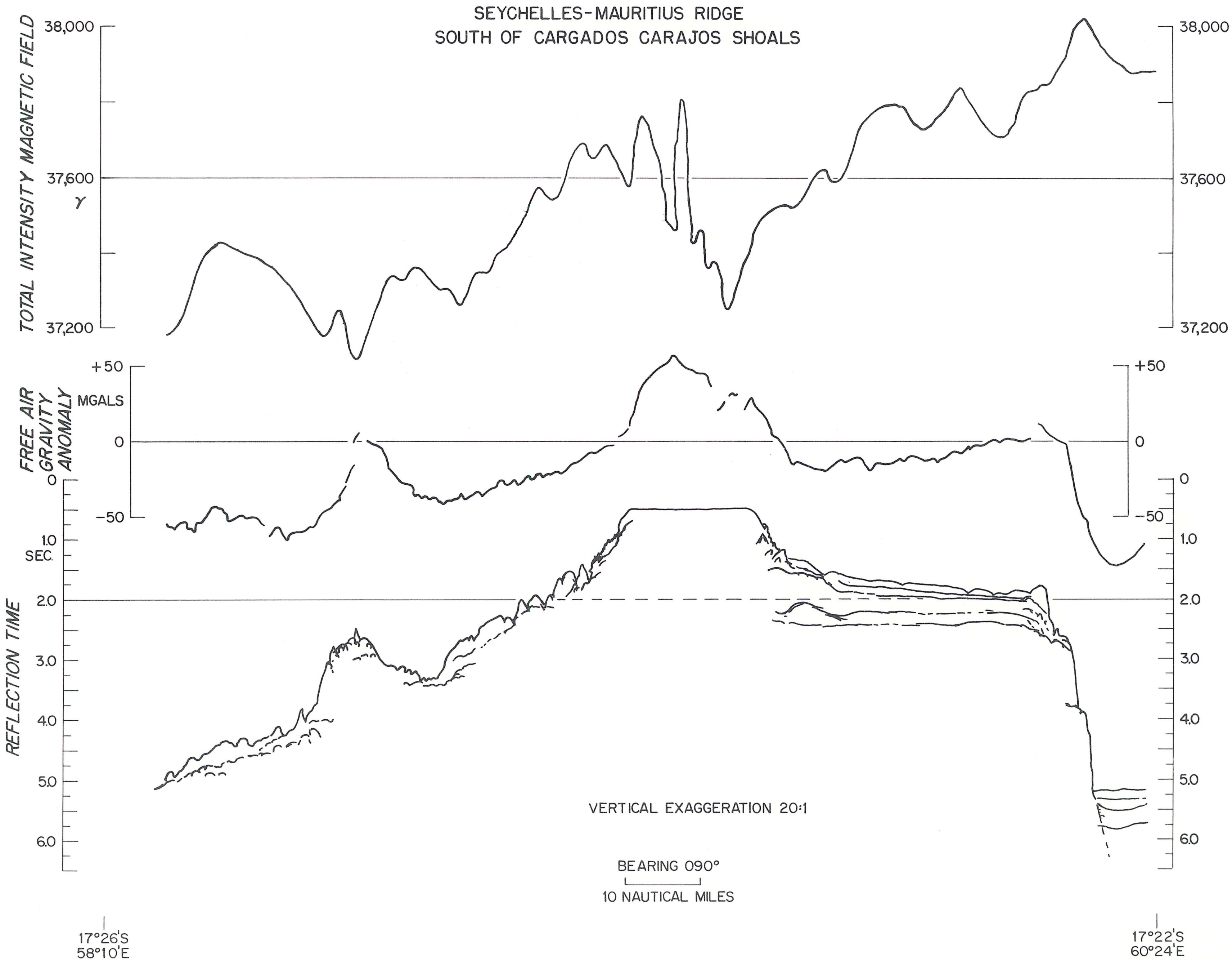


Fig. 14. Seychelles-Mauritius Ridge (South of Cargados Carajos Shoals).

Figure 15 shows a portion of a mosaic of underwater photographs covering about a half mile of the southwest slope of Saya de Malha Bank at 1100 fathoms depth. The mosaic shows quite clearly that a considerable area of the bottom consists of outcrop of nearly horizontally layered rocks. In light of the dredged material these rocks are considered to be limestone. Ripple marks indicate current activity at this depth.

d) Discussion.

It is reasonable to postulate that the northern part of the Seychelles-Mauritius Ridge is structurally different from the southern part. In the former, layered structures, probably sedimentary in origin, occur beneath the central part of the Ridge. No evidence for sedimentary layering is found on Saya de Malha Bank nor beneath the central part of the Ridge to the south. The magnetic anomalies associated with the northern Ridge (Fig. 11, profiles 1 - 3) are weaker than those to the south and are apparently associated with a local structure, a small topographic high near or on the western margin of the Ridge. South of Saya de Malha Bank magnetic anomalies of 400 gamma or greater are associated with the western margin of the Ridge and with the central portion south of Cargados Carajos Shoals (Fig. 12, profiles 5 - 7). Shor and Pollard, (p. 49, 1963), in a discussion of seismic refraction data from the Seychelles and Saya de Malha Banks, suggested that the difference between the two areas might be explained by the presence of a "linear volcanic ridge (similar to the Hawaiian Ridge) extending from Mauritius through Cargados Carajos shoals to Saya de Malha Bank, caused by volcanic outpourings from a line of weakness in the ocean floor". They further suggested that the line continues north and passes close to the Seychelles granitic block, a feature probably much older. The hypothesis is presented here that the magnetic anomaly over the center of Cargados Carajos shoals is continuous with those observed along the western margin of the Ridge as far north as Saya de Malha Bank and is indicative of the trend of a linear feature, probably younger than the Ridge, and possibly representing a more recent zone of weakness and volcanic outpouring. Further, the presence of layered structure on the northern part of the Ridge argues sedimentary origin, older than the volcanic section to the south.

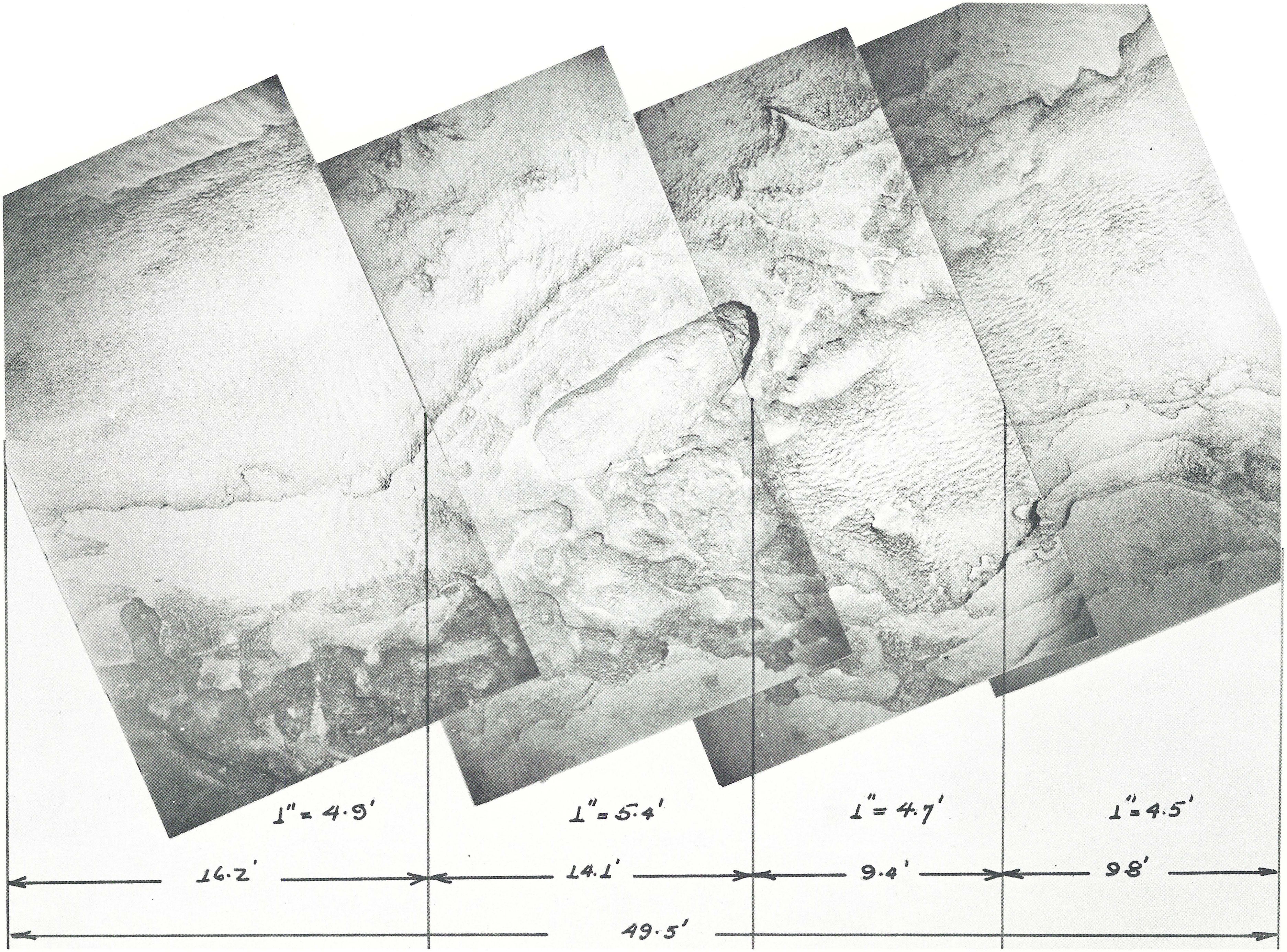


Fig. 15. Western Slope-Seychelles Mauritius Ridge (Photo).

It would be interesting to explore the possibility that the hypothesized younger volcanic ridge structure trends northeast, abuts the sediment covered feature extending south from the Seychelles platform, thus forming an apparently homogeneous topographic feature, and passes east of the older granitic structure, or alternatively that it continues along the arcuate line of the Ridge, becoming more deeply buried to the north, as far as the Seychelles Platform.

This research was jointly supported at the Woods Hole Oceanographic Institution by the National Science Foundation under research Grant GP-2370 and the Office of Naval Research under Contract Nonr-4029.

Analysis of Continuous Seismic Profiling - CHAIN 43, Beirut - Woods Hole (Mr. Jewett).

The chief aim of this work is to analyze continuous seismic reflection profiles obtained in the Ligurian Sea by CHAIN during the period 29 June - 16 July 1964. This work extends a survey of the Northern Tyrrhenian Sea made by CHAIN in 1961 (Cruise 21, Fahlquist, 1963). The profiles were made to discover and delineate features of crustal structure beneath the Ligurian Sea.

CSP records of the entire leg were mounted on cardboard, annotated and photographed. An enlargement of a bathymetric map of the Ligurian Sea (Istituto Idragrafico della Marine-Genova, 1960) will be used as a base map for plotting of topographic, magnetic and gravitational information obtained by CHAIN in that region. A panel model displaying information from CSP records will be constructed on the same base. A collection of Italian and French geological reports on Corsica, Sardinia, the Tuscan Archipelago and the Ligurian Sea has been collected and translated by H. Hodgkins. Information from this collection should aid in the interpretation of the geophysical data collected.

In the deep part of the Ligurian basin ($>$ 2500 m), numerous peaks, possibly volcanic, break through the upper crustal layers. Possible small faults are evident in the records, one being located at the base of the continental slope north of Corsica.

Digital Techniques Applied to the Processing of Seismic Signals (Mr. Caulfield, and Mr. Knott).

Concurrently, with work with analog signal processing, a number of digital computer programs (for the GE 225) have been used to analyze seismic reflection data. So far, digital analysis of signals has only been exploratory. The flexibility of digital computer analysis can be valuable when applied to signal data from selected locations. However, at this time it does not appear to be suitable for on line continuous seismic reflection signal processing in the field.

Studies in Seismic Reflection Analysis (Mr. Olmsted).

A procedure for obtaining sound velocities and layer thicknesses from oblique seismic reflection profile data is being continued (Olmsted, 1963). This method consists of fitting a theoretical travel-time curve plotted against range to the empirical data points. An assumed layer sound velocity is adjusted so that the mean deviation between the theoretical curve and the data points is a minimum. The mean deviation measures the accuracy of fit.

To determine the errors inherent in the method computer programs have been written according to various models of the layered medium and certain perturbations in the travel time, T, are introduced. Analysis is then done upon this simulated data in order to determine the effect of the errors upon the model. The extremes in the parameters specifying the various models are:

1) Points at near range (0 - 5 km)
   Points at far range (5 - 10 km)

2) Deep water (6500 m)
   Shallow water (1000 m)

3) Thick layer (1000 m)
   Shallow layer (100 m)

4) High layer velocity (5.5 km/sec.)
   Low layer velocity (1.8 km/sec.)

When one of these four pairs is being studied the other three are held at intermediate values. Thus while extremes in range (Model 1) are being tested, the water depth is set at 4000 m, the layer thickness at 500 m, and the layer velocity at 3.5 km/sec.

The perturbations introduced are:

a) Purely random errors.

b) An error proportional to travel time T, i.e., a per cent error.

c) An error proportional to X^2/T where X is the range.

d) An error proportional to the secant of the angle of incidence θ_o.

Errors c) and d) are designed to simulate the effects of nonconstant velocities in the water and layers.

To date Model 1 has been studied with the following results:

Range	Perturbation (i.e., Δ T)	Best Velocity	MD (In Milliseconds)
a) near	random } mean of $\lvert\Delta T\rvert$ = 2.5 msec	3.51	2.5
far	random	3.50	2.5
b) near	+5%	3.10	17.2
far	+5%	3.40	8.7
c) near	$+.01\, X^2/T$	3.47	2.9
far	$+.01\, X^2/T$	3.47	0.6
d) near	$+.05 \sec \theta_o$	3.43	2.9
far	$+.05 \sec \theta_o$	3.48	1.5

The actual velocity is 3.50 km/sec. From this table we can see that random errors do not appreciably affect the velocity but increase the mean deviation (MD) by an appropriate amount. A per cent error seriously affects the velocity but the size of MD informs us that something is awry. The errors of type c) and d) are pernicious in that the velocity is affected but that the mean deviation is the same or smaller than that introduced by random errors. Thus a c) or d) type error is masked and we can assume that in actual analysis a slightly nonconstant velocity will be similarly concealed.

Magnetics Program (Dr. Bowin).

Total field intensity magnetic measurements were conducted during the entire International Indian Ocean Expedition (CHAIN #43) using a Varian marine proton precession magnetometer. The towing cables supplied by Varian, however, did not hold up well and, when they became defective, the sensing head was connected to our Dacron strength-membered towing cables. The spark discharge produced by the seismic profiling sound source often caused interference with the Magnetometer signal. This was usually correctable by shutting down the sparker momentarily to make it out of phase with the sampling period of the Magnetometer.

A series of jog-legs were made on the west flank of the Carlsberg mid-ocean ridge in the Indian Ocean to determine the strike of the very large magnetic anomalies occurring there. This venture was quite successful and showed that the anomalies are parallel to the Carlsberg ridge, to the northeast, and the ridge joining the Seychelles Platform and Saya de Malha Bank, to the southwest.

The Magnetometer values are read directly by the shipboard data processing system from a digital counter and are plotted on a profile along the ship's track together with water depth and gravity anomalies.

Magnetics measurements were also carried out using the same system during CHAIN cruise 44 (September - November, 1964), in the North Atlantic Ocean.

Gravity Program (Dr. Bowin).

A calibration program recently devised for automatic determination of the conversion factor for changing of 1711 voltage readings per minute to milligals, first used in the early part of the International Indian Ocean Expedition (CHAIN 43), was improved during the run from Mauritius to Beirut, Lebanon, when an IBM programmer was again aboard the CHAIN.

This new program makes easier the determination of the constant needed for the reduction by the computer of the gravity inputs. Variations in time of this constant, however, are not as yet understood.

The meter drift of our gravity meter (No. S-13) has improved considerably since the two periods of intentional overheating of the gravity meter spring in 1963. During the entire six and one-half months of the Indian Ocean cruise, the drift was about 5 milligals compared with earlier drifts of 10 milligals in two months.

Profiles of free-air and sea-Bouguer gravity anomalies, water depth, and total magnetic field intensity versus distance along the ship's track in nautical miles are now presented in real-time. The profiles are plotted by the shipboard data processing system on a Cal-comp digital plotter.

<u>Heat Flow</u> (Mr. Birch).

Knowledge of the flow of heat from the earth is a necessary boundary condition for discussions of temperatures, thermal conductivities and heat sources within the earth, and for descriptions of the earth's thermal history.

Heat flow is computed as the product of temperature gradient by thermal conductivity. The temperature gradients are measured by thermistor outrigger probes attached to a core barrel (Reitzel, 1963). Thermal conductivities are estimated from an experimentally determined relationship between water content of the sediment and thermal conductivity.

Measurements were made in the Indian Ocean in the Somali Basin and on both sides of the Seychelles-Mauritius Ridge. These measurements are part of a general geophysical survey of the Indian Ocean undertaken in cooperation with other oceanographic groups. The results are in good agreement with others in the Indian Ocean.

In the Mediterranean Sea three measurements were made including one near the island of Stromboli to discover if the heat flow around an active volcano is especially high. The actual heat flow is slightly low, 0.9 $\mu cal/cm^2/sec$, compared to the world oceanic average of 1.48 $\mu cal/cm^2$ sec (Lee and MacDonald, 1963). This low value might be a result of rapid recent sedimentation in the area.

Several measurements were made in and around the Median Valley of the Mid-Atlantic Ridge between 42°30'W and 45°30'N to find out if the Ridge has heat flow as high as the East Pacific Rise (Von Herzen and Uyeda, 1963). There heat flow as high as 8.4 $\mu cal/cm^2 sec$. has been found. No values were obtained in the Median Valley because the apparatus was repeatedly damaged on the rocky bottom. A measurement a few miles east of the Median Valley showed slightly low heat flow, 0.9 $\mu cal/cm^2/sec$.

Work was started to convert from the present 2-probe system of gradient measurement to a 3-probe system. This allows checking the linearity of the temperature gradient and will increase our chances for good stations.

A new system of free-fall heat probes is being designed. This system should save much time in local surveys and obviate use of ships with deep-sea winches.

Bottom Photography (Mr. Johnston and Mrs. Gallagher).

The objectives of the bottom photography program are:

1) To photograph selected areas of the ocean floor in order to:

a. aid in the location of sites suitable for rock dredging
b. show bottom-living animals and their environment
c. allow linkage of bottom types with types of sound recorder.

2) To print and store the photographs in easily retrievable form for future reference.

3) To mount for analysis bottom photographs of the THRESHER area.

Stereo pairs of photographs are taken with EG & G cameras mounted 39 inches apart and focussed at 24 feet. The film used is generally Kodak Plus X. Illumination is provided by EG & G strobe lights which flash every ten seconds. Towing speed during lowerings varies from 0.5 to 2 knots.

The films are developed at sea in a Debrie Rapid Film Processor, and printed on-shore with a Logetronics Enlarger. The latter, first used by us in August, can print up to four hundred prints daily on a continuous paper roll. The paper is processed and dried in the Smith Film Developing Outfit. This procedure results in an output of prints much larger than was previously possible.

Eighteen camera lowerings were made in the Indian Ocean, Mediterranean Sea and North Atlantic Ocean during CHAIN cruise 43. Detailed locations of camera lowerings may be found in the journal for this cruise (in preparation).

Since the installation of the Logetronics Enlarger about 1500 prints, from various cruises, have been produced, of which 75 per cent have been mounted. Where possible, prints were mounted as uncontrolled mosaics.

Number and origin of prints mounted are given in the following list.

CRUISE	LOWERING		
ATLANTIS II 6	1	309 pairs 28 single	THRESHER Search Continental Slope
	4	447 pairs 53 single	THRESHER Search Continental Slope
CHAIN 38	2	213 pairs 152 single 351 center	THRESHER Search Continental Slope "
	3	237 pairs 175 single 385 center	" " "
	6	488 pairs 56 single	" "
	7	206 pairs 25 single	" "

CRUISE	LOWERING		
CHAIN 39	2	95 single	SE of Bermuda
ATLANTIS II 3 (60° rig)	1	257 pairs	THRESHER Search Continental Slope
ATLANTIS II 5			
(7 May)	4	394 pairs	THRESHER Search
(13 May)	3	67 pairs	Continental Slope
		35 single	"
Total prints mounted during this period			2618 pairs 1355 single
Total now in file			25, 686 pairs 12, 226 single

Pictures remounted from punch cards:

ATLANTIS 260	1	377 pairs 21 single
	2	102 pairs 67 single
	3	247 pairs 25 single
	4	212 pairs 12 single
	6	403 pairs 13 single

Bathymetry (Mr. Dunkle, Miss Hays and Mrs. Witzell).

During this period three cruise navigation reports were completed. They are as follows:

ATLANTIS II Cruise 1	WHOI Ref. No. 64-9
CHAIN Cruise No. 36	WHOI Ref. No. 64-10
CHAIN Cruise No. 39	WHOI Ref. No. 64-24

Each report contains track charts, records of depths recorded and nature of observations made.

The Woods Hole Oceanographic Institution plotting sheet series of ten base charts is in its final step of completion and will be used in all navigation reports from now on.

B. Geophysical Instrumentation

Multi-moored Subsurface Buoy (Mr. Savage).

A three-phase program has been undertaken to design, build, and test a practical buoyant structure that offers substantially greater locational precision to deep-ocean surveying than has heretofore been available to oceanographers.

A three-phase project was instituted in March 1964:

1. Basic engineering analysis of the positional reliability of submerged, taut-wire buoyant structures, both single and multi-moored. This analysis has been completed. It presents quantitative substantiation that a submerged, multi-moored system, with buoyancy added to the mooring cables to offset the cable weight, will withstand extreme sea and current conditions with excursions of this system being limited to a small percentage of those indicated for a single-moored system of comparable buoyancy.

The following abbreviated table compares the predicted transverse excursions for a given size of main buoy of four different configurations for a single-versus a triple-moored system.

TABLE I*

Main Buoy Shape	Excursion for Single-Mooring System	Excursion for Triple-Mooring System*
Sphere	2,919'	22'
Oblate Ellipsoid (2 x 1)	748'	12'
Oblate Ellipsoid (4 x 1)	551'	11'
Oblate Ellipsoid (8 x 1)	375'	10'

* Mooring Depth = 15,000 ft. * Current at Main Buoy = 5 kts.
** Net Buoyancy = 8,000 lbs. *Current below Main Buoy =0.5 kts. (avg.)

A statistical analysis of motions of a multi-moored system that might be caused by surface waves was made. For an 8,000-lb. net buoyancy system, moored in 15,000 ft. of water, with suitably designed components, the probability of horizontal motions greater than 5 ft. caused by a State 6 sea was less than 0.01% when the main buoy was placed 100 ft. below the surface.

A series of water tunnel tests were undertaken at the Massachusetts Institute of Technology Propeller Tunnel to determine a desirable main buoy configuration for the system, and the results of these model tests were incorporated in the analysis.

The results of the mathematical analysis were programmed in an IBM 7094 Computer to facilitate the input of a wide range of variables. It is believed that this analysis will be of general use for buoy system design because it presents the means of tailoring a buoy system's design and size to expected conditions of depth, current, desired rigidity, and other variables.

2. Detailed design and construction of a full-scale, test structure.

This phase of the program is in progress. One of the key parts of this design is the installation procedure which must be such that an accurate duplication of the design geometry can be made at sea with present oceanographic vessels and equipment. At this juncture, an installation procedure is under consideration which appears feasible.

3. Installation and full-scale test of a multi-moored buoyant structure.

Paralleling the detailed design of the buoyant structure, the system is being adapted to make specific current and acoustic measurements which will make research use of its indicated rigidity. These measurements will be used as research data for the cooperating oceanographers as well as to measure the system's engineering performance.

The present target date for the full-scale installation and test of this instrument-buoyant structure is July 1965.

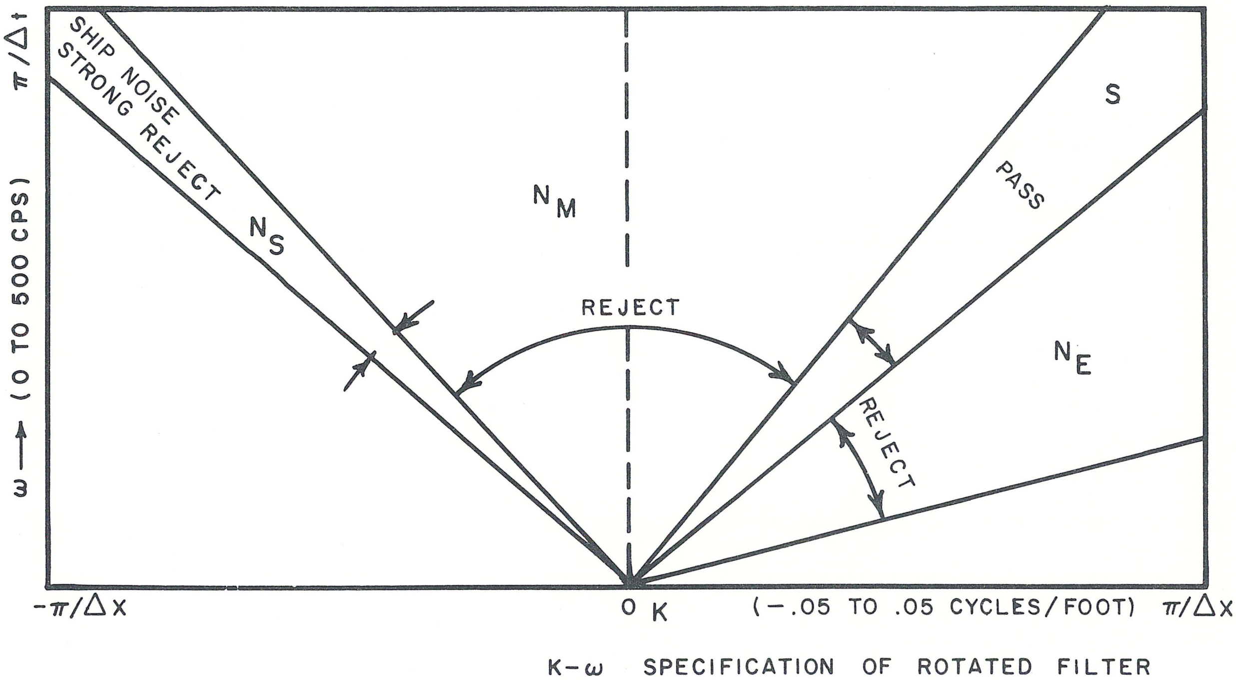
Application of Linear Filter Theory to Towed Hydrophone Arrays (Dr. Beckerle).

Over the past few years the use of continuous seismic reflection profiling with a towed array and a sparker sound source has revealed many layers beneath the ocean bottom. During the past year emphasis has been given to theoretical investigations which would improve the signal-to-noise ratio of weak subbottom reflected signals under a subcontract with Geoscience Inc. A theoretical study of simultaneous filtering in space and time domains of the signals received from a towed ten hydrophone array has been underway to determine the signal-to-noise advantages. The method of filtering under consideration in principle can preserve signal wave shape while at the same time reject noise known to be distributed in an arbitrary fashion in the temporal frequency-spatial frequency domain.

One method of designing such a filter involves the use of a multiple tapped delay line specific to each hydrophone in the array. After suitable gain adjustments the outputs of all of the taps from the delay lines are added together to obtain the undistorted filtered signal. The specification of such a filter is advantageously presented by spectrum level contours drawn on a spatial frequency-temporal frequency domain. Such a filtered domain is shown in the upper figure where the temporal frequency $\omega = 2\pi f_s$ is given as the ordinate and the spatial frequency $k = 2\pi f_s$ is given along the abscissa. All lines drawn through the origin $\omega = 0$, $k = 0$ define a specific direction of approach to the array. Although the line of the array of hydrophones has its major pass band directed vertically downward, the filter can be rotated as shown in Figure 16a. This has the advantage that sectors of noise may be better defined by more filter coefficients. Signal and noise weights may be assigned to the several sectors indicated to specify their relative importance. The signal sector is given a weight of one. There are three noise sectors: one for ship noise, N_S; one for the sector between the ship noise and the signal, N_M; and one for the sector on the other side of the signal sector, designated N_E. The calculated spectrum level contours for an array of ten hydrophones with five taps on each delay line for the case of ship noise equal to twice the signal and for the noise in the other sectors equal to one-half the signal is shown on Figure 16b. A number of similar diagnostic diagrams have been computed. Further analysis of this type will continue based on noise measurements made on a towed array during this past summer. A good portion of array noise is a turbulent flow noise resulting from water movements passing the hydrophones. An experimental program is underway to improve the design of the array of hydrophones in order to reduce this flow noise. We expect to have some tests of the performance of such a filter technique in improving signal-to-noise on towed arrays of hydrophones during 1965.

The Matched Filter Correlator and Associated Equipment (Mr. Knott, Mr. Caulfield and Mr. Lynch).

The application of matched filter techniques to the analysis of seismic reflection data led to the construction of a new unit which was to have, like the first, a 40 millisecond (see WHOI Ref. No. 63-40, p. 10) delay line, but 40 rather than 20 taps and a wider bandwidth of 20 to 300 cps rather than 20 to 150 cps. Problems with response which, for the most part are now solved arose in the design and construction. Gain equalization along the line was at first difficult to attain because it was found that the response of the ten solid state amplifiers inserted at regular intervals in the line did not have sufficiently flat response. Larger coupling capacitors have been inserted and a small amount of negative feedback has been introduced which results in improved response of 47 to 365 cps rather than 60 to 140 cps at the 3 db downpoints. Gain equalization has been



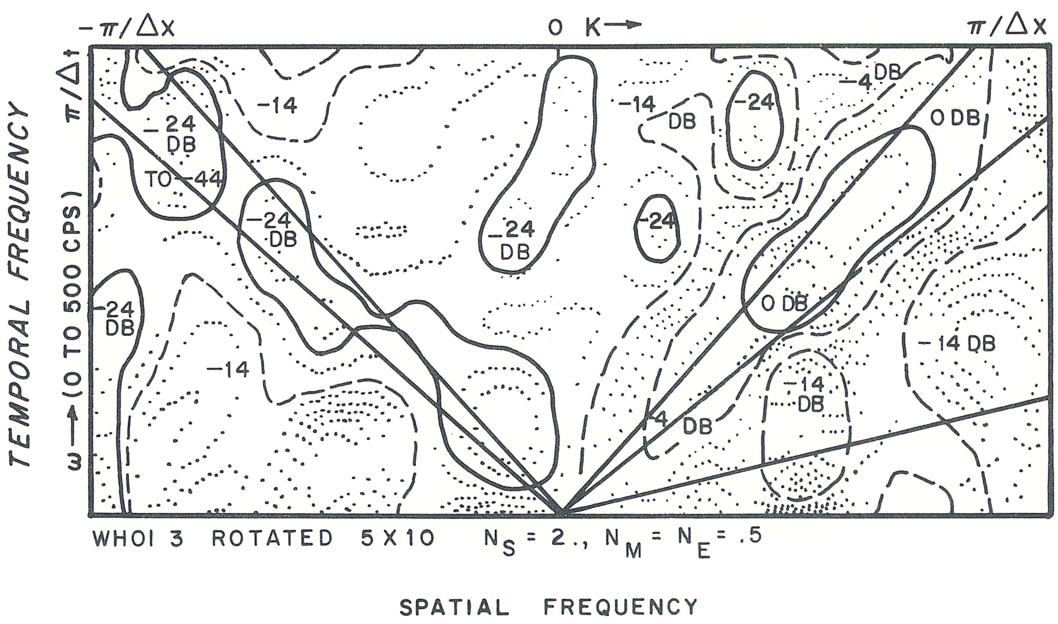


Fig. 16. Spatial and Temporal Frequency Spectrum Level Diagram.

established at a point wherein the difference in the frequency response of the amplifiers is at a minimum.

This matched filter correlator has to date been applied only to data recorded on magnetic tape. The prototype was used only in the field on-line in real time. In working from tapes, real time is, to varying degrees, lost, and therefore, some decrease in effectiveness is expected. If the waveform to which one correlates is an idealized prediction of the spark waveform and does not take into account the delay of the sea surface reflection, correlation with the sea floor reflection is not very effective. Another approach is to cross correlate against a typical received signal selected from the data of interest. Any such sample is mixed with noise so a number of manipulations, i.e., selection of samples, filtering, and averaging, must be done before the required waveform can be set in the delay line. The evaluation and the application of the matched filter correlator are being pursued concurrently with the analyses of various data.

Individual squaring, level discriminating, and integration units for use with matched filter correlator have been previously reported, the following reports a new Precision Graphic Recorder (PGR) amplifier to better adapt this recorder to the matched filter output.

Hydrophone Array System (Mr. Dow, Mr. Nowak, Mr. Grant and Mr. Carter).

Experimentation with towed hydrophone arrays for seismic profiling is continuing. When used in conjunction with sparker or thumper sound sources, these arrays discriminate against noise generated by the ship and by surface waves in favor of bottom and subbottom returns.

The underwater section of the array system includes a 10 element crystal array comprised of five receiving and five transmitting elements, a five channel transistorized preamplifier and a multi-conductor neutrally buoyant towing cable which serves to connect the array to the ship.

In the ship's laboratory the preamplifier signals are passed through a special five-channel line amplifier (five channel suitcase) and thence broadband to a multi-channel tape recorder and through filters to a precision graphic recorder.

A small pulse transmitter keyed by the PGR drives any one of the transmitting elements in the array through matching networks. The surface reflected pulses are detected by the receiving elements and fed to the recorders. Since the time interval between transmitted and received signals is proportional to the depth of the array, a continuous recording of this depth is presented along with the bottom profile.

Following construction and sea trials of one such system on CHAIN Cruise #43 to the Indian Ocean, a second complete system including a spare array and cabling was constructed and installed on ATLANTIS II for Cruise #11 to Puerto Rico. Certain changes found desirable on the CHAIN cruise were incorporated into the new system. The gear was exorcised and tested on the first leg of the cruise and operated successfully except for difficulties with the internal construction of one of the tow cables. Design of subsequent cables has been modified to eliminate the trouble.

Portable Seismic Amplifier (Mr. Dow and Mr. Grant).

A single channel portable seismic line amplifier somewhat similar electronically to channels incorporated in the five-channel suitcase amplifier (Described in WHOI Ref. No. 64-50) has been designed and constructed. The new unit has been used at sea in conjunction with a towed array by Dr. K. O. Emery's Geology group, and was found very satisfactory.

A New Signal Amplifier for the PGR (Mr. Lynch and Mr. Caulfield).

A new signal amplifier was designed and constructed for the Precision Graphic Recorder (PGR) which is used to display the matched-filter output. This amplifier is capable of working below 10 cps, where the conventional PGR amplifier introduces distortion. It is a solid state device having two conventional transistor gain stages feeding a Darlington circuit made up of a driver stage and a power output stage directly coupled to the recording helix and paper. A variable bias control provides level discrimination. The new solid state amplifier is not as yet a multi-purpose replacement for the wide dynamic range tube-type PGR amplifier.

Short Pulse Echo Sounder (Mr. Dow and Mr. Carter).

A high powered short pulse echo sounder has been constructed and is undergoing sea trials. This is a simplified and inexpensive version of the unit used for high definition bottom search on ATLANTIS II during the hunt for the submarine THRESHER.

However, the full capabilities of this instrument as well as the Inverted Echo Sounder have not been realized because most commercial transducers of suitable size, weight, efficiency and depth range cannot handle the high peak power developed by the transmitter.

Therefore, an experimental ceramic transducer supplied by the Bosch Arma Corporation is being tested with a version of the new transmitter suitably modified for the purpose. Preliminary tests indicate that the transducer is quite efficient, at least for surface work, but it has not, as yet, been subjected to the pressure cycling life test required for evaluation of its performance capabilities in the deep ocean.

Digital Depth Measurement (Mr. Hess).

As a direct outgrowth of the automatic depth system designed by Wilharm and Knott a completely digital depth measuring system is under construction. This system is planned to be completely automatic in operation (i. e., should not require constant monitoring) and will provide continuous depth information to shipboard computers. In addition, a visual readout is presented for monitoring purposes.

The system consists basically of a master crystal controlled oscillator and count down from which transmit commands and received signal gating are derived. The received signal is gated to eliminate spurious returns from fish or other midwater targets. A 0.5 second "window" is provided for echo detection. This "window" is self-adjusting in time to follow gross changes in bottom contour while the fine detail is indicated by the position of the echo in the window. When the echo either lags or leads the center 0.1 second of the window a command is generated to advance or retard the window position. This method effectively blanks out extraneous midwater targets while allowing for rapid changes of depth.

Readout is visual for local monitoring and electrical for feeding a computer. The units used are tenths of fathoms obtained by counting cycles of a 4 kc/s tone derived from the master crystal oscillator. Conversion to other units of measurement is readily accomplished by changing the frequency of the counted tone.

Flow-film Camera and Printer Facility (Mrs. Senefelder and Mr. Hoskins).

The flow-film camera is being used to build a microfilm library of echo sounding and seismic profiling data taken on cruises and in preparing some of these data for publication. The cruises filmed during this period were CHAIN 39, 41, 42 and portions of ATLANTIS II 8 and CHAIN 43. A file of film positives for reference and distribution is now complete.

Using this facility it is planned to make a composite of all the echo sounding profiles on a cruise, reproportioned to a common vertical and horizontal scale, for inclusion in our cruise reports. This has been done for the echo sounding and magnetometer traces for the portion of ATLANTIS II Cruise 8 from Woods Hole to Bombay (July to September 1963). In this reproportioning, a variable speed transmission on the copy transport is used to compensate for changes in the ship's speed over the ground and the different gatings and writing speeds of the Graphic Recorder. The final presentations (North Atlantic, Mediterranean, Red Sea, Western Indian Ocean) were cross-sections, 30-inches wide, and presented the sea floor with a vertical exaggeration of 10:1. From these cross-sections, other cross-sections with a vertical exaggeration of the sea floor of 100:1 were made. Portions of the original recordings were successfully reproduced with the relative dimensions altered by 17:1 in making this second cross-section. This much change, however, results in considerable loss in resolution.

A variable speed motor was installed in place of a fixed speed motor on the drive of the paper processor. This permits varying the development time of the photographic papers from 40 seconds to 6 minutes. An apron which fits over the drying drum was added to facilitate even drying of short lengths of paper. A system for air-wiping the paper as it travels from bath to bath to reduce chemical carry-over was installed but is not yet operable.

Terminal Connector for Multi-Conductor Plastic Tow Cable (Mr. Stillman).

One of the requirements of cable employed for towing Magnetometers is that it must be free of magnetic materials. A tow cable incorporating aluminum conductors, a pre-stretched dacron strain member and multiple layers of plastic sheathing is presently being employed for this purpose. A terminal connector, capable of holding the strain member to its breaking point has been fabricated at WHOI. To prevent differential slippage of the other components, the connector also grips each conductor and sheath.

HYDROACOUSTICS

Near-Surface Sound Transmission (Mr. Caulfield, Mr. Bergstrom and Dr. Beckerle).

Acoustic experiments were carried out in the Norwegian Sea during August of 1960 to determine the signal level of the direct arrivals from explosive sources detonated near the surface in a sound velocity structure which exhibited a double channel. One of the purposes of the experiment was to investigate how much sound energy originating in one of the sound channels becomes coupled into the other sound channel.

Information about the physical characteristics of the water in which the experiments were performed was obtained from a thermistor chain which recorded the water temperature at various levels and from an N. B. S. sound velocimeter which measured the sound velocities. With the information from these two instruments, it was possible to construct a velocity profile of sound velocity versus depth as plotted in Figure 17. There is a strong, but thin, sound channel having an axis at 120 feet located above a weak, but broad, channel extending between 178 feet and 359 feet. This deeper channel is complicated in that it contains within it a small secondary sound velocity channel.

The measurements were taken during a two-ship operation in which the R/V CHAIN acted as the receiving ship and the R/V SVERDRUP acted as the sending ship. One kilogram charges were dropped from the sending ship and were fused to detonate at depths of 80 feet and 230 feet in two

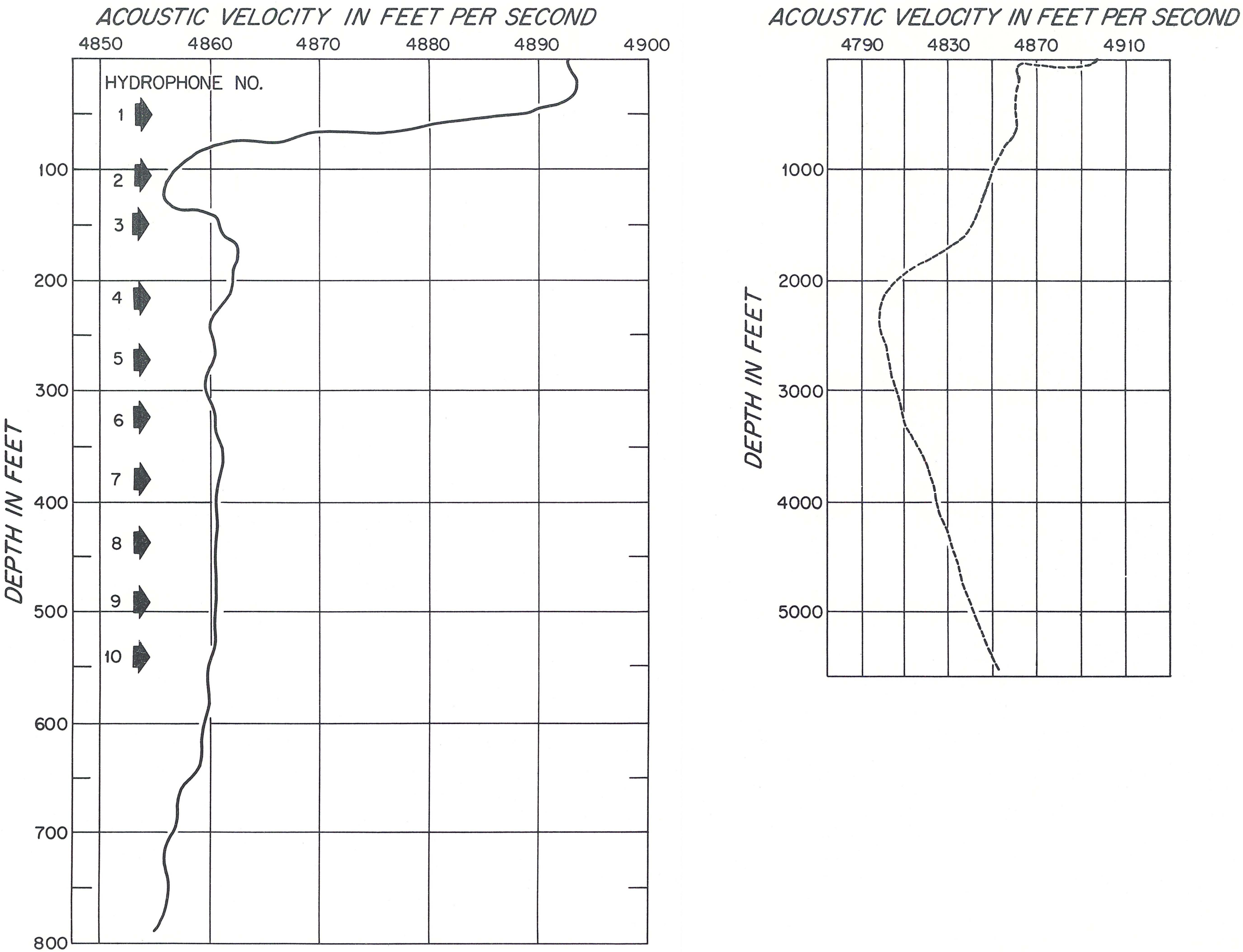


Fig. 17. Velocity Profiles.

separate runs. The source depth for the 80 foot deep explosive run is located above the strong, but thin, sound channel, while the source depth for the deeper explosive run was located within the weak, but broad, sound channel. The acoustic energy of the first arrivals from the detonations was recorded simultaneously on a 14-channel Ampex tape recorder from ten hydrophones mounted in the Woods Hole Oceanographic Institution thermistor chain and spaced at 50 foot intervals. Measurements were made over a range of about 10 nautical miles. Although initial work was hand computed, the use of a high-speed digital computer resulted in a substantial improvement in data handling and detail in the presentation of the contours. The energy level contours for the 1.0 to 2.0 kilocycles per second band from the explosive sources fired below the strong channel with its axis at 120 feet, but within the weak channel, are shown in Figure 18A. The results of theoretical calculations are presented in Figure 18B.

The contours in both of these figures were adjusted for spherical spreading. Several features should be noted in the upper figure:

(A) The concentration of sound in the depth range of the deeper, broad, sound channel.

(B) The relatively small amount of sound energy captured by the strong, but thin, sound channel at 120 feet.

(C) The presence of sound energy all along the range run received by the 50 foot hydrophone. In regard to the last observation, ray theoretical calculations indicate that rays only reach the 50 foot deep hydrophone out to a range of one or two miles.

Since the field observations indicate some energy gets into the region close to the surface where rays do not penetrate, a coupling mechanism must be present. For example, reflection of the rays from a rough sea surface could scatter the sound into the small 30-foot deep surface duct. A second mechanism involves diffraction of lower frequency sound into the shadow zone region. A third possibility involves scattering of refracted rays by variable microstructure in the sound velocity profile all along the transmission path.

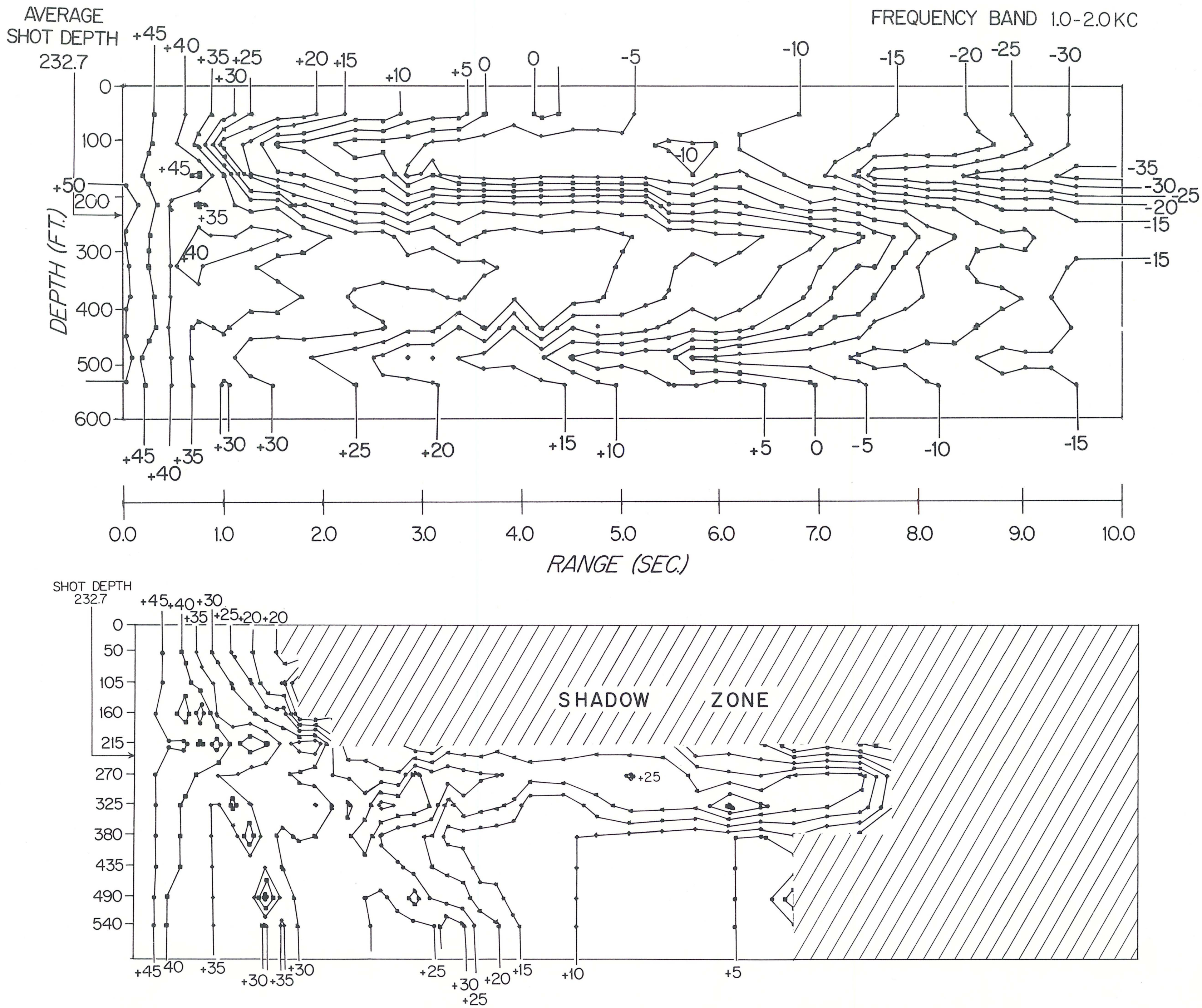


Fig. 18. Energy Level Contours.

The reason that sound energy from these deep bomb signals is not captured by the strong, but thin, sound channel at 120 feet is clear from ray theoretical concepts. All rays issuing from the source must follow Snell's Law and this law does not allow rays from the source to become horizontal within the strong but thin sound channel. Scattering of rays into this channel by microstructure in the sound velocity profile is apparently not a very important mechanism.

A computer program was developed to construct a theoretical ray diagram from which energy levels could be computed with similar range and depth parameters as were used for the field data. Figure 18B presents equal energy contours computed from the ray diagram for the run of deep explosive sources. Except in the shadow zones (as mentioned above) where the rays do not penetrate, there is reasonable agreement between the contours obtained from the field data and the theoretical computations.

Only a partial analysis of these experiments have been made so far. We are continuing to study these measurements to gain a better understanding of the coupling of sound energy between two sound channels.

PHYSICAL OCEANOGRAPHY

A. Investigation and Analysis

AT II-11

Velocimetry (Mr. Payne, Dr. Beckerle, and Mr. Stillman).

a) Introduction

The following descriptions of sound velocimeter profile measurements made over the ocean area between Bermuda and the Antilles this summer was sponsored by ONR Contract Nonr-2866. However, since the investigations are pertinent to this ONR Contract , Nonr-4029 also, brief summaries are presented below.

b) Sound Velocity Structure of the Ocean between Bermuda and the Antilles (Mr. Payne, Dr. Beckerle, and Mr. Stillman).

Some preliminary observations have been made as a part of continuing study of the sound velocity structure as a function of geographical coordinates in the broad ocean area between Bermuda and the Antilles. One of the objectives of this study is to determine the long term stability of the sound velocity structure in this part of the Atlantic Ocean. To date, two surveys of the area have been made, one in July - August 1962 and one in the same months of 1964. The shapes of sound velocity profiles made at the same locations in the two studies and at neighboring locations differed in the main thermocline. This difference increased from south to north affecting the horizontal as well as the vertical component of the sound velocity gradient. These changes could have a significant effect on the long range stability and detection ranges of sound transmission systems. It has been found instructive to draw isovelocity contour charts from the data on horizontal sections for several depths and on vertical cross sections through the area in describing the sound velocity characteristics.

c) Transition Region in Sound Velocity Contours South of Bermuda
(Dr. Beckerle, Mr. Payne, Mr. Wilson and Mr. Stillman).

An iso-sound velocity contoured vertical cross section chart obtained from a sequence of sound velocity profiles made in July 1964 along a southwesterly course from Bermuda has revealed the existence of a mid-ocean transition region extending down to a depth near the sound channel axis. The deep ocean boundary is located at about 30°N 67°W which happens also to lie between the trade winds and the westerlies. The region of this boundary is characterized by a change of more than 200 meters in the depth of iso-sound velocity lines within a horizontal distance of about 70 nautical miles. This transition region exhibits lower sound velocities near the surface which may be related to one of the many meandering surface thermal fronts observed for several years in the area. The sound velocity profiles reveal a secondary sound channel having an axis approximately 200 meters deep. In the vicinity of the boundary region this sound channel is affected by warmer water rising from 500 meters depth to the north of the transition region and flowing over the colder water to the south. Just the opposite condition prevails for surface thermal fronts located in the area in which warmer water to the south rises over colder water to the north. It is conjectured that an upwelling of water as deep as 500 meters in this region could be a source of internal waves.

B. Oceanographic Instrumentation

Thermistor Chain Developments (Mr. Tasko).

The importance of the recorded data gathered by a towed thermistor chain to the studies of acoustic transmission and internal waves is well established. However, the size and weight of the original towed chain of thermistors placed severe limitations on the depth at which thermal fluctuations could be measured. Therefore, a lighter towed cable, using aluminum fairings was developed. This cable is known as the Thermistor String.

Analysis of thermistor string recordings requires statistical computation, and this in turn has led to the development of a digital recording thermistor system. This system automatically and sequentially measures the output of each thermistor in the string and records the measurements on magnetic tape. The thermistors are wired in a series and they are fed by a constant current D. C. power supply. The advantage of a constant current system is that any change in the overall resistance of the series of thermistors occasioned by defective thermistors, etc. does not affect the readings of the remaining elements.

The potential drops across the thermistors are read out by a high impedance integrating digital voltmeter which also practically eliminates random noise and pickup. The wiring system minimizes the effect of cable and contact resistance since current in the leads feeding the high impedance system are minute. Any two thermistors, in addition to being scanned, may be continuously monitored by the two strip chart recorders incorporated in the system. During scanning, all measurements are visually displayed on nixie tubes incorporated in a digital voltmeter with a memory system. This memory system allows checking of the transducers for gross error even during high speed scan. By slowing the scan rate, or by manually pulsed scanning, the individual transducer readings and station numbers may be observed.

... plugged into molded sockets along

Aluminum fairings are used to allow towing at normal ship's cruising speed. In order to keep the towed cable nearly vertical under water a heavy fish is attached at the bottom. The fish weighs 2250 pounds and is made of steel. A version of the inverted echo sounder was experimentally mounted in the fish for accurate depth measurement.

As mentioned in the last report, a part of this system was put aboard the R/V CHAIN at Beirut, Lebanon, underway tests of the faired cable and inverted sounder were conducted during this cruise.

A major system test was carried out on ATLANTIS II Cruise 11 during the summer. Despite the short string of thermistors, a considerable amount of valuable information on internal waves and thermal structure was gathered with the system. The ATLANTIS II Cruise #11 was funded under ONR Contract Nonr-2866 and NSF Grant GP-1123. Although analyses of observations will be reported under these contracts, we also plan to present in ONR-4029 Progress Reports those findings which are pertinent to this contract.

Lack of a primary standard for checking and calibrating thermal equipment at sea has presented problems. A new type of quartz crystal thermometry system has been employed experimentally as a ship's standard and also for measuring surface water temperatures at the bow of the vessel. Initial results have been gratifying and since the system also lends itself well to automation and computer work, additional experiments and modifications have been planned.

Inverted Echo Sounder (Mr. Dow, Mr. Grant, and Mr. Carter).

The Inverted Echo Sounder is an acoustic depth meter designed to measure with high precision the depth of other instruments lowered with it into the ocean. It consists of a high-powered short pulse transmitter and a fixed tuned receiver mounted side-by-side in water-tight cases and coupled to a common transducer beamed toward the surface. The pinger emits short 12 kc pulses and the surface reflected pulses are detected by the receiver and passed up on oil well logging cable to the ship. The time interval between transmitted and received pulses, corrected if necessary for the sound velocity profile, are proportional to the depth.

Two improved versions of these instruments together with one readout system for the ship were constructed during this period. The new models have a simplified and more rugged internal structure than earlier types and are more easily serviced. A new trigger tube has been incorporated which provides an increase in transmitted power, and has a considerably longer life than the miniature units previously employed.

A more compact external frame for the deep units has been designed. This frame surrounds and protects the echo-sounder and velocimeter, but reduces the overall volume of the package to approximately one-half that of previous models. The frame structure has been simplified and should prove considerably less expensive to fabricate and assemble. An experimental unit is under construction.

The original type of frame will still be required when the instrument is used for bottom survey work.

GENERAL INSTRUMENTATION

Shipboard Data Processing System (Dr. Bowin)

In early May an IBM programmer rejoined the R/V CHAIN at Mauritius, Indian Ocean, having earlier departed the I. I. O. E. cruise at La Spezia, Italy. The programmer brought with him an IBM 1717 output printer (typewriter without a keyboard) which has been used since Mauritius as the main typewriter for listing the data obtained in real-time. The 1620 console typewriter and the main laboratory logging electric typewriter are alternate modes of output in event of temporary servicing of the 1717 output printer. The 1620 console typewriter is not buffered and therefore it is not satisfactory for normal operation.

During the leg from Mauritius to Beirut, Lebanon, the IBM programmer continued to improve the computer program. Most notable was the completion of the logic for the real-time plotting of bathymetry, free-air and sea Bouguer gravity anomalies, and the earth's total magnetic intensity on a digital plotter (California Computer Products, Corp.) annotated with scales, time, date, and position information.

Difficulties in utilizing the three logging typewriters which occurred throughout the International Indian Ocean Expedition (CHAIN Cruise 43) were finally solved prior to the following cruise (CHAIN 44). The correction procedure was primarily one of changing the priority rating of the three logging typewriters, but why this eliminated the previous problems remains a mystery.

Variable Tuning Fork for Use with the Precision Graphic Recorder (Mr. Witzell).

A variable tuning fork is used to facilitate the visual correlation of received underwater acoustic signals on the Precision Graphic Recorder (PGR). Most sonar signals are transmitted at a constant repetition rate, but the received signal travel time varies either from the change in range of the transmitter to the receiver or change in travel time of a reflected signal. When the travel time changes, signals recorded on successive sweeps are skewed, making visual correlation more difficult. If the velocity of the recording sweep is decreased, as the travel time increases, or vice versa, the recorded signals can be made to assume a relatively straight line, parallel to the margin of the paper. Several devices have been developed to accomplish this by varying the sweep speed. Normally the helix drive motor is controlled by a 60 cycle precision source consisting of a 240 cycle fork followed by a divider string and a power amplifier. However, by appropriate switching, this motor may also be driven from an external source. If the frequency of this source can be varied over a small range, the R. P. M. of the synchronous motor and resulting sweep speed may be controlled as desired. However, the stability of the source for any given setting must remain high. A device which meets these requirements is described in this report.

This unit consists of a 60 cycle tuning fork which may set to operate anywhere in the region from 59 - 61 cycles. The tines of the fork are placed in the gap between the extended pole pieces of a standard hand magnet. When the strength of the magnetic field between these pole pieces is varied, the fork frequency changes accordingly. In the hand magnet this field is controlled by rotating one permanent magnet inside the other so as to produce either an additive or cancellation effect. The deviation from the 60 cycle norm can be determined from the relative slope of the scale lines which are derived from a separate tuning fork precision source within the PGR, and recorded along with the acoustic signals.

Electronic Programmers for the Precision Graphic Recorder (Mr. Lynch, Mr. Coleman and Mr. Knott).

Electronic programmers for the Precision Graphic Recorder determine the number of transmitted pulses of the echo sounder, the delay time before the returning echoes are recorded, and the number of sweeps recorded.

Considerable counting flexibility was afforded in the first four electronic programmers constructed, but small subtle differences in logic existed between them. They are now being standardized.

Two later units incorporating smaller components and having logic different from the early models are also being modified to conform as closely as practicable to the standard. A technical report is in progress.

Printed Motor PGR Drive (Mr. Hess and Mr. Witzell).

A contract has been let for the construction of a printed motor drive system to replace the existing synchronous motor-gear box drive now in use on Precision Graphic Recorders.

The immediate advantages to be realized are elimination of a complex multiple gear and clutch transmission and introduction of a variety of sweep speeds limited in number and accuracy only by the frequencies used for reference. It therefore becomes feasible to have virtually any sweep speed on the recorder. For instance, sweep speeds may be electrically changed between feet, yards, meters, and fathoms as well as time intervals without mechanical devices.

The principle of the system is a many pole D. C. motor of extremely low inertia, coupled directly to the recording drum. An optical tachometer generator providing up to 4000 hits per revolution is mounted on the motor. A closed loop servo system compares the output of the tachometer cycle-by-cycle to a reference oscillator and generator control power to the motor to match phase. Phasing under dynamic load can be accomplished to a few degrees of the electrical cycle giving approximately 1 part in 25,000 linearity and repeatability from turn to turn of the recorder drum. This is better than the printing resolution of the recorder and therefore not noticeable.

The extremely high starting torque of this type of motor shows promise for impulse start of the recording drum to synchronize it to sound sources whose firing instant is not predictable to a sufficient degree to allow synchronization with a continuously running recorder. This technique will be investigated.

Further Design Improvements in Air Driven Cable Puller (Mr. Hess).

The air driven cable puller described in the last report has since been used extensively at sea (see Fig. 19). Little trouble has been encountered in the mechanism in spite of over 6 months exposure to salt atmosphere and spray. The "tugger" as it has come to be called, was in use almost daily during this period and saved countless hours of valuable ship time. The fact that the machine is so simple to operate has made it even more useful as virtually anyone can step up to it and operate it with but a few moments' instruction.

The tugger has been coupled to a reeling machine (also air driven) forming a complete cable handling system. The reeling machine consists of a frame upon which a variety of sizes of cable shipping reels can be mounted (see Fig. 19). A driving motor (1.25 HP air) is positioned to drive the edge of the reel by means of a pneumatic tire. The motor-wheel assembly is adjustable in position so that a wide range of reel diameters are accommodated.

Air to the reeling motor is provided from an auxiliary outlet on the tugger and is controllable from there. The reeling motor, being unable to pull the cable is normally supplied with a continuous supply of air so that it keeps slight tension on the line at all times. It is then necessary only to operate the throttle on the tugger to reel in a cable.

Cable tensions of up to 500 pounds at speeds up to 450 feet per minute are available.

This system has become a standard part of the shipboard continuous seismic profiling equipment.

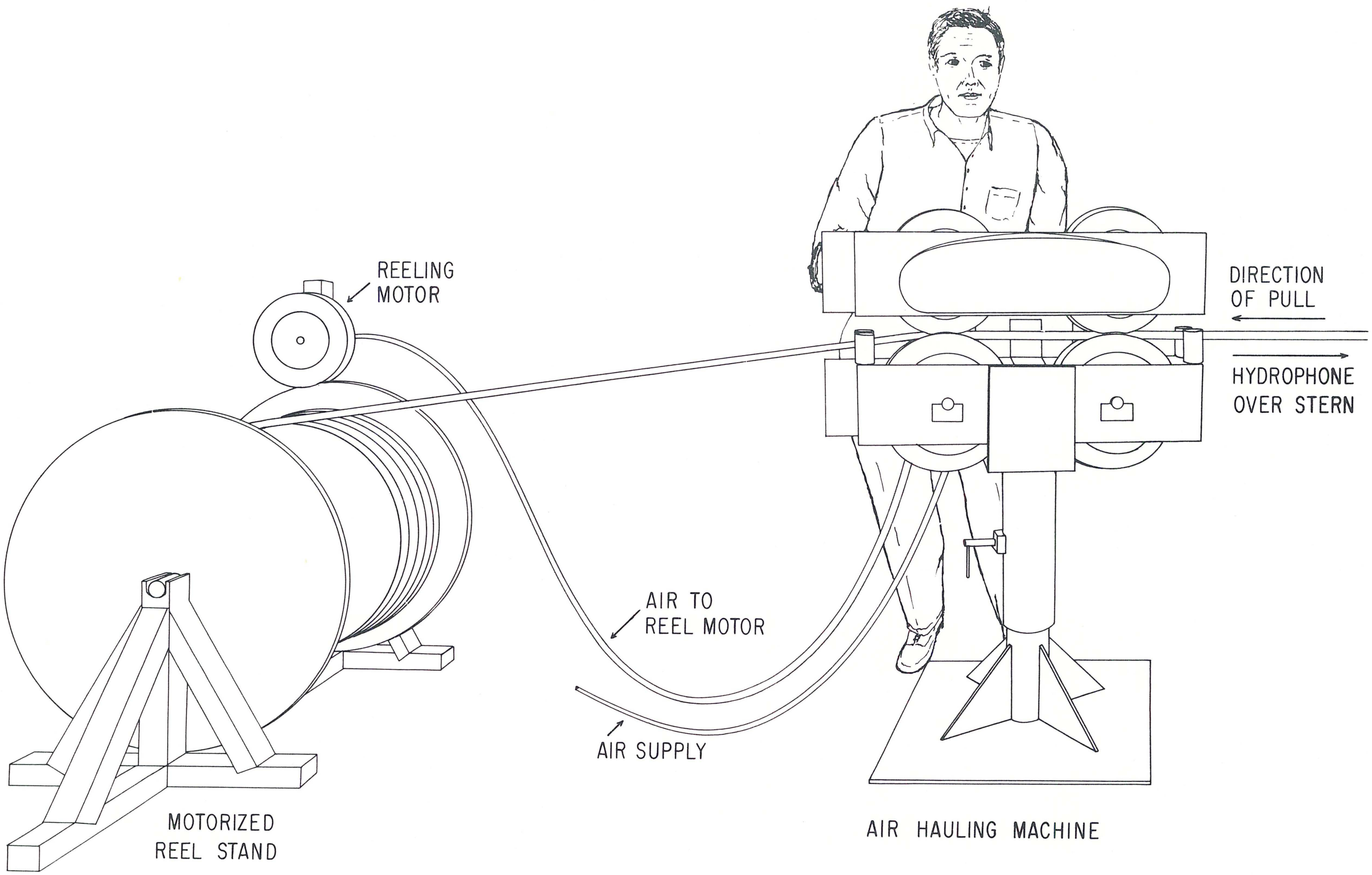


Fig. 19. Air Driven Cable Puller.

<u>Photographic Enlarger</u> (Mr. Johnston).

A new Logetronics enlarger is being used in the processing of the THRESHER Search films. The great advantage of the Logetronics enlarger over the manual enlarger became immediately apparent. It is now possible to produce a straight run of about four hundred individual and different prints a day. The prints are run off in a continuous paper roll in contrast to the individual sheets used previously. When five to eight hundred prints are made the roll is then processed and dried on the paper processor in the Blake building in about two hours. This all lends itself to a system of rapid and efficient processing of our film. There is however a bit of concern regarding the short washing period provided by the paper processor and action is being taken to include a "hypo" cleaning tank to the unit to insure the proper washing and cleaning of prints.

Since the installation of the Logetronics enlarger we have been able to produce over twenty-five hundred prints of which about twenty-five per cent have been mounted and some have been assembled into mosaics.

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APPENDIX

Visitors

Dr. B. Lallemont	ASW Research Center, La Spezia, Italy
T. N. Reynolds	A.U.W.E. - Portland, England
C. P. Glover	AVCO Radio Corp.
J. F. Holmes	"
R. A. Wagner	"
R. G. Sanders	Aeroflex Laboratories
H. F. Hamburg	Aircraft Accessories
L. A. Farrington	Alden Electronics Inc.
Dr. C. B. Officer	Alpine Geophysical Co.
Henry Hoagland	American Research & Development Corp.
R. M. Foose	Amherst College
Dr. E. R. Brownscomber	Atlantic Refining Company
R. E. Smith	" "
George O'Sullivan	Booz, Allen Applied Research
D. J. Ginnes	Brogan Associates

R. O. Doherty	C. E. I. R. - Boston, Mass.
D. H. Quam	California Company
Carl Hartdegen	Columbia University - Bermuda
A. Piip	" "
L. E. Tyson	" "
H. J. Dumas	Cornell & St. George, Inc.
S. W. Kennedy	" "
Donald Saling	Daystrom Electric Co.
D. W. Berger	Del Electronics Corp.
Klaus D. Berger	"
Stanley Krongold	"
R. A. Campbell	Deutsch Electric Corp.
R. Blasing	Dymec Instrumentation
E. E. Dinowitz	Dynamic Research Co.
H. B. Silverman	"
Dr. D. L. Coursen	E. I. DuPont de Nemours, Gibbstown, N. Y.
W. A. Ellis	Eastern Scientific Co., Providence, R. I.
K. Ballingall	Electronic Associates, Inc.
Dr. M. P. Foache	French Navy
Edward F. Clark	Friden, Inc.
R. F. Wynch	General Electric Co., Syracuse, N. Y.
J. N. Gallerath	Geosciences, Inc.
S. M. Simpson	"
R. A. Wiggins	"

Dr. W. B. Heroy, Jr.	Geotechnical Corp.
J. H. Hamilton	"
D. R. Salvos	Gerber Scientific Instrument Co.
M. G. Bernard, Jr.	Gulton Industries, Inc.
R. Carlson	"
C. W. Thomas	Hawaii Institute of Geophysics - Stanford Univ.
T. Tawuioto	Honeywell Mfg. Co.
J. W. Hokanson	International Business Machines, Inc.
C. E. Lovell	" "
R. A. Penkethman	" "
J. Gallagher	J & J Associates
A. J. Fergusson	Johnston Laboratories
R. J. Leyden	Lamont Geological Observatory
R. E. Sheriden	"
Paul Anderson	Minnesota Mining & Mfg. Co.
Dr. Gordon Lill	National Science Foundation
M. C. McLean	" "
R. K. Sibley	Naval Recontech Suppcon.
J. L. Mero	Newport News Shipbuilding & D. D. Co.
M. Halberstam	Newtek, Inc.
Cdr. W. W. Lasley	Office of Naval Research - Washington, D. C.
Dr. A. E. Maxwell	" "
Joseph McGrath	" - Boston, Mass.
Admiral J. J. Lynch	Quonsett Naval Base
J. J. Lynch	Unified Data Service, Inc.
B. Wutz	" "

Dr. J. D. Bleckae	United Electra Dynamics
R. E. Barnett	U. S. Corps of Engineers
W. D. Ford	"
R. W. Hohl	"
D. E. Good	U. S. Navy Electronics Laboratory
Miner W. Buell	U. S. Naval Oceanographic Office
Robert A. Wuse	" "
H. Deferron	U. S. Naval Research Laboratory
Capt. G. W. Folta	U.S.N. Underwater Sound Laboratory - Op. Div. 4
Lt. O. C. Pickel	" " "
Dr. M. N. Hill	University of Cambridge - Cambridge, England
Prof. Eugene Allmendinger	University of New Hampshire
Dr. J. C. Steinberg	University of Miami - Institute of Marine Sciences
G. R. Bernard	University of Texas
H. V. Fisher, Jr.	Sandia Corp.
William Hereford	"
R. W. Raitt	Scripps Institution of Oceanography
G. G. Shor	" "
V. Withington	Sikorsky Aircraft Co.
John Donovan	Sperry Gyroscope Co.
Lloyd Kaufman	Sperry Rand Research Center
Dr. S. C. Crane	Stanford Research Institute
Sherman Ades	Yewell Associates
R. A. Perry	"
R. White	"

Personnel

R. H. Backus	Senior Scientist
J. B. Hersey	"
A. C. Vine	"
W. E. Schevill	Associate in Oceanography
J. C. Beckerle	Associate Scientist
Elizabeth T. Bunce	"
C. O. Bowin	Assistant Scientist
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Unclassified

Geophysical investigations were carried out aboard R/V CHAIN in the Indian Ocean, the Mediterranean Sea, and the North Atlantic Ocean. Observations underway were continuous seismic profiling, gravity, magnetic, and echo sounding measurements. At stations rocks were dredged, cores were taken (about 10 meters long,) photographic montages of the sea floor were made, and the sound velocity of the water was measured as a function of depth.

Progress is being made in filtering and correlation techniques for seismic profiling, while seismic receiving arrays were improved to make them quieter.

The analysis of internal wave data is continuing, but further observations at sea will be required in order to fully understand the mechanism of propagation.

Seven papers were published during this period and thirteen were submitted for publication. These papers are concerned with seismic profiling, seismic refraction profiles, sediment ponding, sound transmission, thermal fronts, and biological papers dealing with sound production by marine mammals and deep-sea fish natural history gained from bottom photographs.

A new thermistor string intended to replace and improve upon the original thermistor chain was the principal new instrumental development.

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3. REPORT TITLE

OCEANOGRAPHIC AND UNDERWATER ACOUSTICS RESEARCH CONDUCTED DURING THE PERIOD 1 MAY - 31 OCTOBER 1964.

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Progress Report 1 May - 31 October 1964

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6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
March 1965	74	18

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
Nonr-4029(00)NR260-101 b. PROJECT NO. and Nonr-3243(00)NR260-108	Reference No. 65-12
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